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International Journal for Modern Trends in Science and Technology, 8(08): 33-40, 2022

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST0808006
Available online at: http://www.ijmtst.com/vol8issue08.html

Slope Stability Analysis of an Embankment Resting on Soft Soil

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To Cite this Article
K.Sreejasri and M.Harilal. Slope Stability Analysis of an Embankment Resting on Soft Soil. International Journal for Modern Trends in Science and Technology 2022, 8(08), pp. 33-40. https://doi.org/10.46501/IJMTST0808006

Article Info
Received: 25 June 2022; Accepted: 30 July 2022; Published: 04 August 2022.

ABSTRACT

The aim of this study is to investigate the standard fill and pond ash embankments with reinforced and unreinforced conditions using Slope/w module in GeoStudio 2021. Due to rise of industrialization and urbanization, the slope stability of embankments constructed with locally available materials became the foremost important area for geotechnical engineers. The stability of those embankments could also be improved by adopting geogrid reinforcement with native soil or by replacing the embankment with Pond Ash. The current study is on the slope stability analysis of a road embankment with crest width of 8m, side slopes of 2H:1V and height 5m resting on 10m thick c-φ soil..The Mohr-coulomb material is employed to model the soils and Morgenstern-Price method is employed to search out the factor of safety (FOS) for a critical slip surface. Geogrids are placed at different layers in normal and pond ash embankments and therefore the optimal arrangement is found out. It is found that the factor of safety is increased by 43.8% when the traditional fill is replaced with pond ash as the angle of internal friction is higher for pond ash. The optimal arrangement of geogrid at base together with pond ash fill embankment gives a highest factor of safety of 2.834 and just in case of normal fill, the highest factor of safety is 2.62 with the arrangement of geogrid at 3rd and 4th layer together.

KEYWORDS: Geogrid reinforcement, Geostudio, Pond ash, Factor of safety, C-Φ soil, Stability

1. INTRODUCTION

In earlier days about 3000 B.C earth structures and embankments were constructed using soil as a construction material, this selection of soil was done by trial and error procedures. In the early 1800's in England, Thomas Telford and John Macadam had constructed roads and railways based on scientific principles. One of the principles was to raise the foundation above the surrounding ground so that water would not soften the subgrade. With the construction of railroads in the beginning of 1830s, new problems were developed because of the flat grades and long radius curves required and the higher loadings imposed on the subgrades. Royal Commission of the Swedish State Railways was appointed in 1913 to develop procedures to avoid these failures. The report of the Commission in 1922 was detailed about soil properties and geotechnical analyses in determining slope stability, undisturbed soil sampling, and laboratory shear testing. The terms like density, moisture, strength, compressibility, and other soil properties were studied clearly by the mid-1930s, and their relationships were established for various soil types during the subsequent 30 years. Zoned embankments with specified materials utilized in different portions of the embankment, came into common use.

An Embankment is a structure made of wall or stone or bank of earth to prevent flooding area of a river or to hold a road or railway over a vicinity of low ground. Embankments are constructed using non aerated, water proofed and compacted material to provide support to the formation and raising of roadways or railways above the level of ground surface.

Based on the types of construction materials used, embankments are classified into various categories like reinforced embankment, earth fill embankment and rockfill embankment. Generally these embankments are constructed using soil, aggregate, rock or crushed paving materials.

In order to produce firm foundation for the embankment and also to facilitate proper drainage and prevent saturation of embankment, coarser fill materials are placed at the bottom or base of the embankment and on the top portion high quality, well compacted subgrade material which is capable of resisting imposed wheel loadings and deflections on pavements are used.

Gradation, unit weight and specific gravity, shear strength, compressibility, corrosion resistance and permeability are some of the required properties of materials to be used in embankments.

1.1 SLOPE STABILITY

An unsupported, inclined surface of soil mass is assumed as Slope. Slope stability is defined because the assessment or calculation of a slope on what proportion it can resist the shear stress. The stability of a slope depends on shear strength and shear stress.

1.1.1 TYPES OF SLOPE FAILURE

- Rotational Failure
- Translational Failure
- Compound Failure
- Wedge Failure

1. Rotational Failure

This type of failure occurs by rotation along the slip surface. There is both downward and outward movement of the soil mass. The surface is non-circular just in case of no homogeneous soil. There are three types in Rotational failure they are

- Toe Failure
- Toe failure is that the commonest kind of failure. The failure occurs along the surface which passes through the toe.
- Slope Failure

Soil failure occurs along a surface that intersects the slope above the toe. It occurs when a weak plane exists above the toe

- Base Failure

Base failure occurs along a surface that passes below the toe. It occurs when a weak stratum lies beneath the toe.

2 Translational Failure

Translational Failure occur just in case of infinite slopes and layered material. It occurs along failure surface parallel to the slope. The shape of the failure surface is influenced by the presence of hard stratum at a shallow depth below the slope.

3. Compound Failure

It is the combination of translational failure and rotational failure. Compound failure occurs when a troublesome stratum underlies at considerable depth below the toe.

4. Wedge Failure

Plane failure or wedge failure or block failure occurs along an inclined plane. It occurs when a difinite mass of soil becomes separated. It's almost like translational failure. It can also occur during a finite slope consisting of two different materials or during a homogeneous slope having cracks or the other plane of weakness.

1.2 GEOSYNTHETICS

Reinforced material used in construction of embankment is "Geosynthetics" These are natural or artificial products used along with soil as they perform many functions namely separation, reinforcement, barrier, drainage, surface erosion control, containment and protection. They are mostly found in geotechnical, transportation, marine, environmental, hydraulics, construction including roads, railways, embankments, retaining walls, canals, waste landfill, breakwaters, mining, revetments etc...

1.2.1 TYPES OF GEOSYNTHETICS:

Geotextiles

These are polymeric fibrous materials used for separation, filtration, fluid barrier, reinforcement, construction of roads, harbour works and breakwaters. These are subdivided into woven, Non-woven, Knitted and Stich-bonded fabrics.

Geonets:

These are planar products consists of ribs in two directions and apertures are of diamond shape. Ribs act as small check dams to hamper the surface runoff which decreases the erosion effect. Thickness of geonets is additionally large compared to geogrids. These are employed in road construction and their repair to enhance paved surface by decreasing the cracking effect and corrugation of roads.

Geomembrane:

These are impermeable membranes controls the flow of fluid through it so used as canal lining, landfill lining and tunnel lining. These stabilize the earth and secure landfills from containment of hazardous or municipal wastes and leachates.

Geosynthetic clay liners:

These consists of a core of bentonite clay present between layers of non-woven geotextiles used to control soil erosion and used as sub-base support for railway tracks, container yards and road bases and used between geomembranes in landfills within which bentonite expands when fluid leaks through punctured geomembrane and closes the gap.

Geocell:

It is a 3D honeycomb cellular structure used to improve the load carrying capacity of soft subgrades. Geocells creates a stiff slab to distribute load over large area and increases shear strength and bearing capacity and reduces deformations. These are employed in construction of retaining structures, railway embankments and pavement

Geocomposites:

Combination of two differing kinds of geosynthetics which performs entire functions of geosynthetics like separation, drainage, filtration and reinforcement.

Geogrids:

Geogrids are polymeric products formed by means of intersecting grids employed in the construction industry as a reinforcing material. The polymeric materials like polyester, high density polyethelene and polypropylene are the main composition of geogrids. These are sheet like products with open apertures which have good interlocking with soil and high strength. Uniaxial products are used as reinforcement layers in retaining walls and embankments. Biaxial products are used in road bases, below rail tracks, ground reinforcement

These are good in tension and has higher ability to distribute load over large area. The apertures in geogrids helps in interlocking the aggregates or soil placed over it. The soil structural integrity increases and promotes soil stabilization. It can be installed in any weather conditions and no difficulty in availability of material and flexible in nature. It helps in increasing the soil strength and load bearing capacity. They're more durable and highly resistant against environmental influences so it can reduce the maintenance cost. Geogrids solve the issues encountered with soft backfill soil or sloping ground. All these characteristics makes geogrids more demanding in embankment construction.

1.3 INDUSTRIAL BY PRODUCTS:

The common industrial waste materials utilized in road embankments are fly ash, pond ash, blast furnace slag, cement kiln dust, waste plastic bags, etc.

Fly ash:

Fly ash is that the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases.

Favourable properties of fly ash are:

1. Light weight, lesser pressure on sub-soil
2. High shear strength
3. Coarser ashes have high CBR value
4. Additional strength because of self-hardening
5. High permeability
6. Non plastic
7. Faster rate of consolidation and low compressibility
8. Can be compacted using vibratory or static roller

Blast furnace slag:

Blast furnace slag is generated during the melting process in steel making operations. It has been used as a cementitious binder in road construction. Low energy requirement – only grinding of material is required. This provides an excellent potential for profitable use of this waste material and produces alternate binder to cement. It has better strength.

Cement kiln dust:

1. Cement kiln dust effectively improves soil strength and also reduces construction time and costs.
2. When lime is employed as a stabilizing agent, the soil must be remixed and compacted 48 hours after the lime is first applied.
3. When cement kiln dust is employed as a stabilizing agent, the blending and compacting of cement kiln dust

are completed when it is initially applied or within 24 hours.

4.Cement kiln dust is mixed with soil to switch plastic limits or moisture content to supply to desired stabilized properties.

5.Cement kiln dust (CKD) is that the finely divided dry alkaline particulate carried from a cement kiln by the exhaust gas, and captured by the kiln's air pollution control system.

Pond ash:

Pond ash is that the residue after combustion of coal in thermal power plants, so its properties depends upon the coal used and may vary from one power house to other power house.

Properties are:

1. Non plastic material
2. Has potential to suppress the swelling behaviour of soil
3. A decrease in MDD and increase in OMC with addition of pond ash content.

1.4 METHODS UTILIZED IN ANALYSIS OF EMBANKMENTS:

Limit equilibrium method: It is one in all common approaches for analysis of slope stability for both two and three dimensions. This method derives factor of safety and also identifies potential failure mechanism, finds endangered areas, etc for geotechnical situations. There are several limit equilibrium methods like ordinary slice method, bishops method, Morgenstern price method.

Ordinary slice method: In the ordinary slice method the failure is assumed to be an arc with center o and radius r the soil mass is split into slices with the assistance of this method we are going to find the factor of safety. The forces functioning on each slice could also be obtained by considering the mechanical (force and moment) equilibrium for the slices.

Bishop method: The bishop method is usually accustomed find the factor of safety. This method satisfies vertical force equilibrium for each slice and over all moment equilibrium about the center of the surface. The bishops method is a little different from ordinary slice method. The traditional forces interaction between adjacent sides are assumed to be collinear and also the resultant interaction shear force is zero.

Morgenstern price method: Morgenstern price method is a general method developed on the premis of limit equilibrium satisfying equilibrium of forces and Moment acting on individual blocks is required. The blocks are created by dividing on the soil above the slip surface. The Morgenstern price method not only gives us the factor of safety but also gives us the slope displacement.

Mohr coulomb model: The Mohr coulomb model assumes the failure of a plane is controlled by the maximum shear stress and this shear stress depends on normal stress. The failure line of the mohr coulomb is represented as a straight line that touches the Mohr's circle. Mohr coulomb model helps in predicting settlement behaviour of an embankment.

2. METHODOLOGY

Embankment is split into 4 layers shown in Fig.1. Numerical analysis was performed using GeoStudio 2021. The Mohr-coulomb material is employed to model the materials and Slope/w module is used to seek out the critical slip surface. Shear strength parameters of normal fill soil, pond ash and geogrid properties got as input to the software. Entry and exit points are selected. The stability of normal fill and pond ash embankment is analysed without any reinforcement and then with geosynthetic reinforcement placed at 1st,2nd,3rd,4th layers separately,1st and 4th,1st and 3rd layers for both normal fill and pond ash embankments at different layers and factor of safety is measured using Morgenstern-price method. Finally, critical failure surface is identified and therefore the corresponding factor of safety is found.

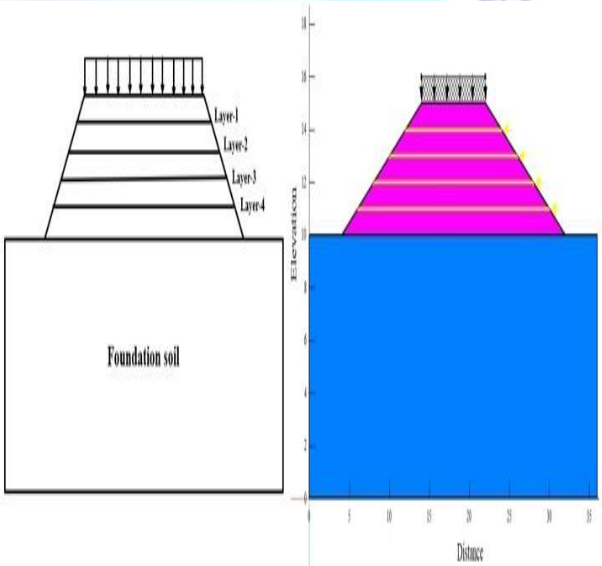

Fig1: Embankment divided into 4 layers

An embankment of crest width 8m with 2:1 side slopes and height 5m has been utilized in this study as shown in Fig. Soil properties, geogrid properties and geometry model are assumed. he embankment is resting on foundation soil (c-) of 10m thick. A surcharge load (Pavement load+ Live load) of 20kN/m³ is applied on the top of the embankment structure. Two styles of fill materials are used for embankment i.e., Normal fill and Pond Ash.

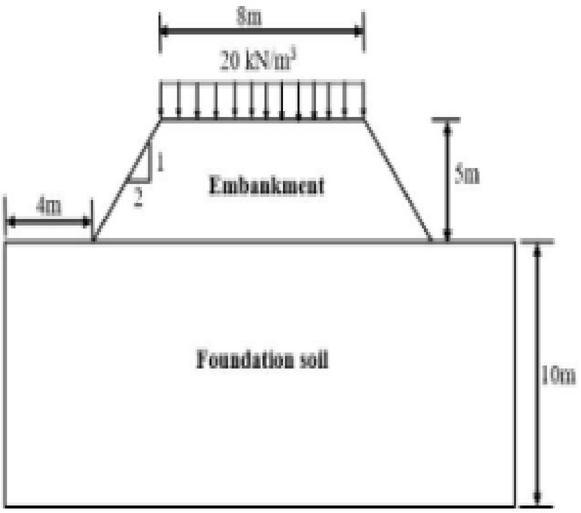

Fig2 : Embankment model

The embankment fill, foundation soil and pond ash were modelled as a Mohr coulomb material and the properties of materials are shown in Table 1 & Table 2 below.

Table 1. Properties of soil and pond ash (IRC SP: 58 1999 for pond ash)

Parameters		**Foundation soil**	**Normal fill**	**Pond ash**
Unit weight (γ)	kN/m³	17	18	13.7
Cohesion (c)	kPa	3	5	0
Angle of shearing resistance (ϕ)	Degrees	13	15	40

Table 2. Properties of Geogrid

Parameters		**Geogrid**
Tensile strength	kN/m	300
Pullout resistance	kPa	600

2.1 Procedure for analysis of factor of safety of an embankment:

➢ GeoStudio 2021 R2 software is opened.

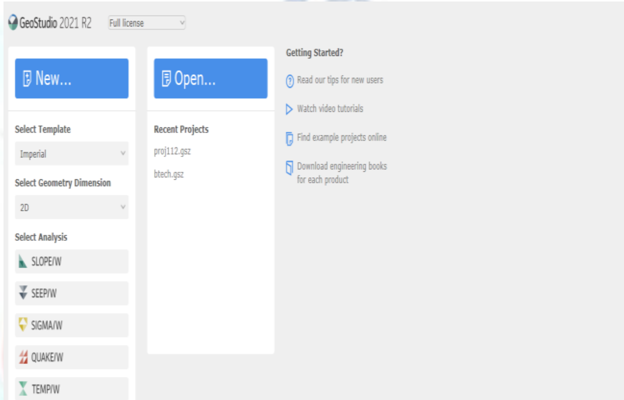

Fig3: GeoStudio 2021 R2 software

➢ After opening the GeoStudio 2021 software SLOPE/W module is selected.

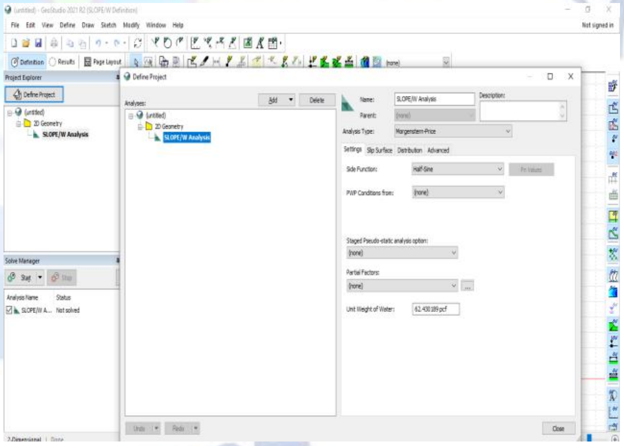

Fig 4: SLOPE/W module

➢ Go to view select units and set the units as per requirements.

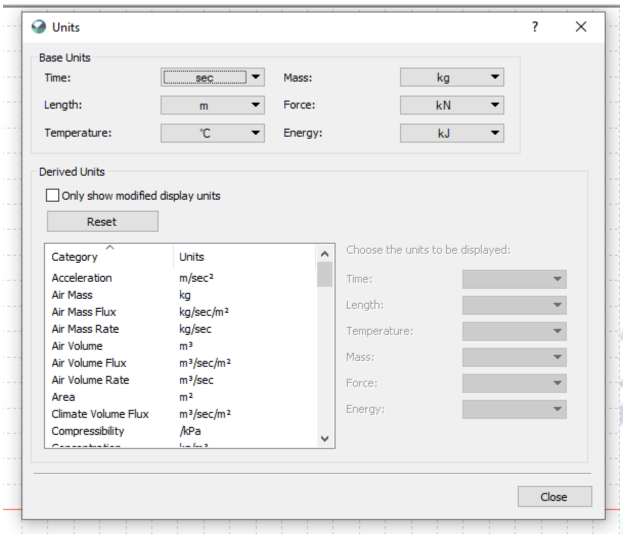

Fig 5: Units

➢ Go to sketch and select axes and fill the requirements.

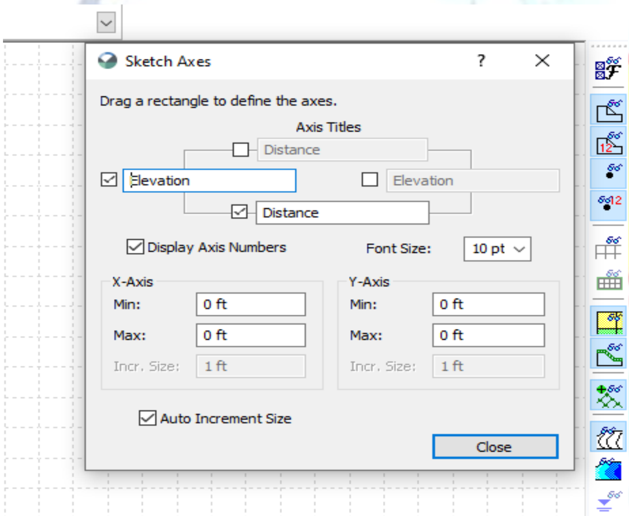

Fig6: Sketch axes

➢ Go to draw and select regions. Click on polygon under domain region.

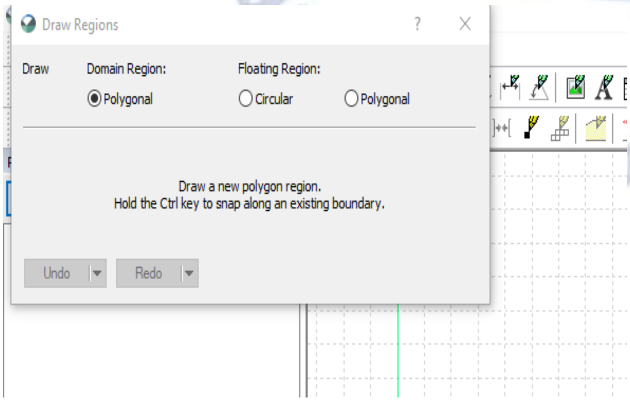

Fig 7: Draw regions

➢ Go to draw select regions and draw the embankment model.

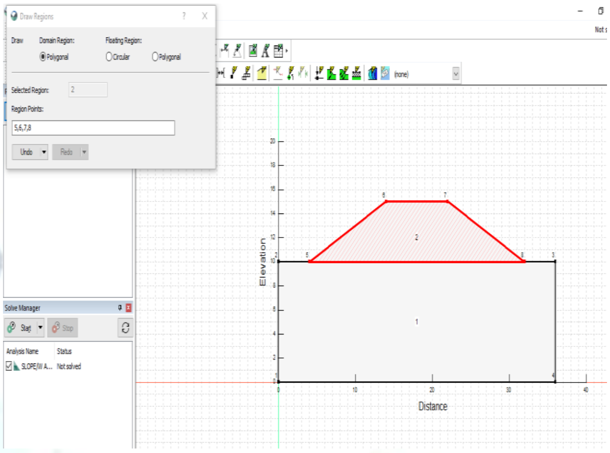

Fig 8: Draw Embankment model

➢ Go to define select materials. Add the materials as per requirements also set their respective colour.

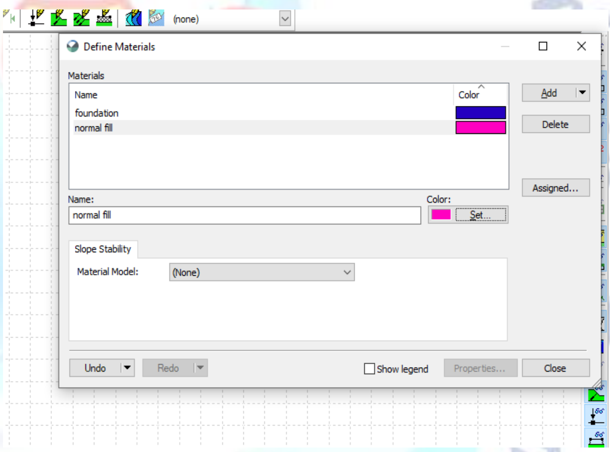

Fig 9: Define materials

➢ Now apply defined materials to the embankment model drawn.

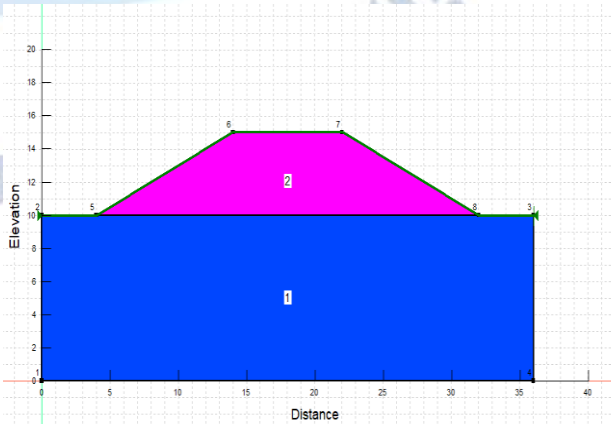

Fig 10: Defined embankment model

➢ Go to draw click on slip surface then select entry and exit and specify its range.

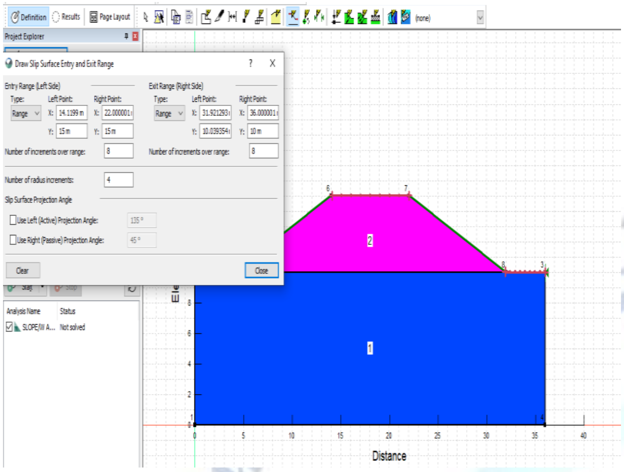

Fig 11: Slip surface of an embankment

➢ Click on start button to get the required results.

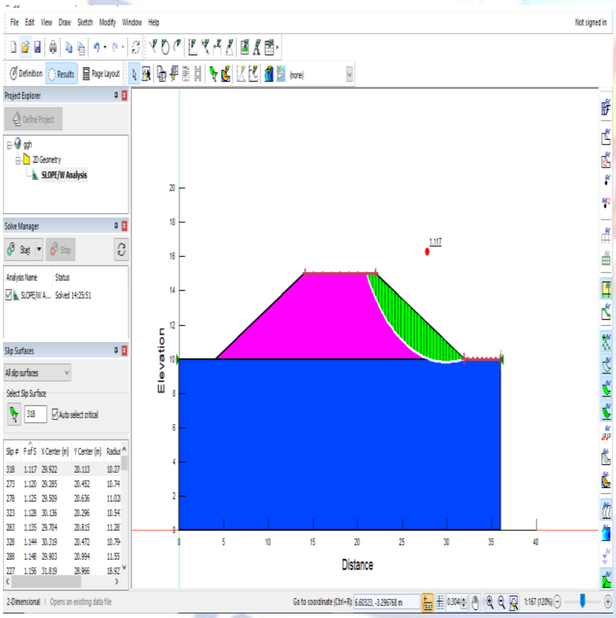

Fig12 : Factor of safety of an embankment model

3. RESULT

Table 3: Comparison between factor of safety of Normal fill embankment and Pond ash embankment with various positions of geogrid layers.

Position of geogrid layer	**Factor of safety (Normal fill)**	**Factor of safety (Pond ash)**
Unreinforced embankment	0.925	1.330
Basal geogrid reinforcement	2.122	2.834
Middle geogrid reinforcement	1.69	2.228
Geogrid Reinforcement at Crest level	1.151	1.607
Geogrid Reinforcement at 1st layer (1m below crest)	1.405	1.850
Geogrid Reinforcement at 2nd layer (2m below crest)	1.603	2.103
Geogrid Reinforcement at 3rd layer (3m below crest)	1.801	2.347
Geogrid Reinforcement at 4th layer (4m below crest)	1.938	2.590
Geogrid Reinforcement at all layers	-	-
Geogrid Reinforcement at 3 layers	-	-
Geogrid Reinforcement at 2 layers	2.62	-

Table 4: Percentage increase in factor of safety of unreinforced Pond ash embankment and reinforced Pond ash embankment when reinforced with geogrid cells at different positions of an embankment.

Position of geogrid layer	**% increase in FOS**
Basal geogrid embankment	113.08
Middle geogrid embankment	67.5
Geogrid reinforcement at crest level	20.8
Geogrid reinforcement at 1st layer (1m below crest)	39.09
Geogrid reinforcement at 2nd layer (2m below crest)	58.12
Geogrid reinforcement at 3rd layer (3m below crest)	76.47
Geogrid reinforcement at 4th layer (4m below crest)	94.74

Table5: Percentage increase in factor of safety of unreinforced Normal fill embankment and reinforced Normal fill embankment when reinforced with geogrid cells at different positions of an embankment.

Position of geogrid layer	% increase in FOS
Basal geogrid embankment	129
Middle geogrid embankment	82.7
Geogrid reinforcement at crest level	24.4
Geogrid reinforcement at 1st layer (1m below crest)	51.89
Geogrid reinforcement at 2nd layer (2m below crest)	73.29
Geogrid reinforcement at 3rd layer (3m below crest)	94.7
Geogrid reinforcement at 4th layer (4m below crest)	109.5

4. CONCLUSION

1. Factor of safety of pond ash embankment increased by 43.78% when compared to normal fill embankment as the angle of internal friction is higher for pond ash.
2. Factor of safety of a Pond ash embankment increased by 39.6% compared to Normal fill embankment when reinforced with geogrid cells at crest level of an embankment as reinforcement imparts tensile strength to the soil.
3. Normal fill embankment shows improvement in factor of safety by 129% and 109.5% on inclusion of geogrid cells at base level and in 4rth layer (4m below the crest) respectively when compared to unreinforced Normal fill embankment.
4. Pond ash embankment shows improvement in factor of safety by 113.08% and 94.74% on inclusion of geogrid cells at base level and in 4rth layer (4m below the crest) respectively when compared to unreinforced Pond ash embankment.
5. As the distance of geogrid layers from the crest level increases the FOS has increased because as the depth increases the impact of load will be lesser.
6. The FOS is higher when the geogrids are placed at 1st and 4th layers in normal fill embankment and pond ash fill embankment.

ACKNOLEDGEMENT

We would like to express our deep sense of gratitude to the professors Dr. P. Dasharatham, JNTUH who are very cooperative and their guidance was invaluable & inspiring in doing this research paper.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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