International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 10 (November 2014) www.ijirae.com

NUMERICAL MODELLING OF HIGHWAY EMBANKMENT BY DIFFERENT GROUND IMPROVEMENT TECHNIQUES

Sabahat A. Khan*
Assistant Professor,
Civil Engg. Deptt., AMU, Aligarh, India

Syed M. Abbas
Professor,
Civil Engg. Deptt., JMI, New Delhi, India

Abstract— *The main objective of the present research was to carry out slope stability analysis of a highway embankment using FEM based software (PLAXIS 2D v8) to model light weight and local embankment fills over a soft subsoil by using fly ash as fill material and installing geogrids under static conditions and then recommend the use of these materials for future designs of light weight embankment sections. The settlement of the embankment was observed and the factor of safety against slope failure was calculated for different embankment materials. Mohr coulomb model was used for embankment material modelling in the FEM analysis. Under static conditions, normal soil reinforced with geogrids was found to improve the factor of safety of embankment to the maximum extent as compared to other embankment materials.*

Keywords— Slope Stability, Ground Improvement Techniques, Embankment, Finite Element Method, PLAXIS

I. INTRODUCTION

Problems due to slope instability are very common on road embankments and cause failure in the road embankments due to the movement of the pavement which results in either large settlement or sliding due to inadequate shear strength. Normal fill can comprise of mix of different soils like silty sand, clayey sand or silty clay etc which are commonly found embankment material at various locations in India. Due to climatic variations, swelling or shrinkage related soil movements commonly occur in the soils underneath the infrastructures such as pavements, embankments and light to medium loaded residential & commercial buildings. In pavements, the soil movement results in settlements, surface cracking and thereby creating difficult driving conditions and also costly rehabilitation and maintenance for the highways all across the country.

In the assessment of slopes, geotechnical engineers primarily use the factor of safety values to determine how close or far the slopes are from failure. Conventional limit-equilibrium techniques are the most commonly used analytical methods. Numerical modelling by finite element analysis techniques with excellent commercial softwares like PLAXIS, GEOSLOPE, GEO5, etc. has made a powerful viable alternative to the assistance of the geotechnical engineer. In this study our aim is to carry out a slope stability analysis of a man-made slope by finite element method based PLAXIS 2D software.

Thermal power plants account for more than 70 percent of power production in India generating large volumes of fly ash. Fly ash is commonly used as a highway material in embankments and approaches. Other than fly ash polymeric materials like Geogrids made of Geosynthetics have also been used in India to prevent settlements under highway embankments. Furthermore use of fly ash with geogrids has been found to be an innovative ground improvement measure in mitigating stresses and settlements induced during earthquakes. Construction of embankments on soft soils like clay with high groundwater level is extremely challenging and often requires prior analysis. Conventional limit equilibrium and finite element are the two common methods of analysis used in geotechnical engineering for designing and predicting the mechanical behaviour of embankments. The main advantages of finite element analysis over conventional limit equilibrium method are that complete interaction of the embankment foundation can be simulated and the mode of failure need not be predetermined.

A study of the behaviour of embankments made with various light weight materials like fly ash and geogrid added to conventional fill materials on clay is presented in this paper. Staged construction of the embankment has been effectively modelled followed by the application of overburden pressure on the structure. The parameters required for modelling of fly ash and geogrid fill embankment has been used from the work of various researchers determined in the laboratory using a prototype embankment.

Finite Element Model

A typical embankment of 8.5 metre crest width with 2:1 side slopes has been chosen for this study. The height of the embankment is 4 metre. The soft clay layer followed by well graded sand layer is assumed to be fully saturated. An overburden pressure of 30 kN/m^2 is applied on the structure. The embankment is constructed on soft clay in two lifts. Height of each lift is 2 metres and construction time for each lift is 30 days. Construction of each lift is followed by a consolidation period of 60 days during which the excess pore water pressure is assumed to dissipate. Time required for the application of overburden pressure is taken as 30 days in the model. The finite element model has been created and analysed using PLAXIS 8.2 Professional geotechnical analysis software.

Owing to the symmetry of the problem, only one half needs to be modelled. 15 noded plain strain elements have been used for discretizing both the embankment as well as the foundation material. The model discretization is shown in Fig 1.

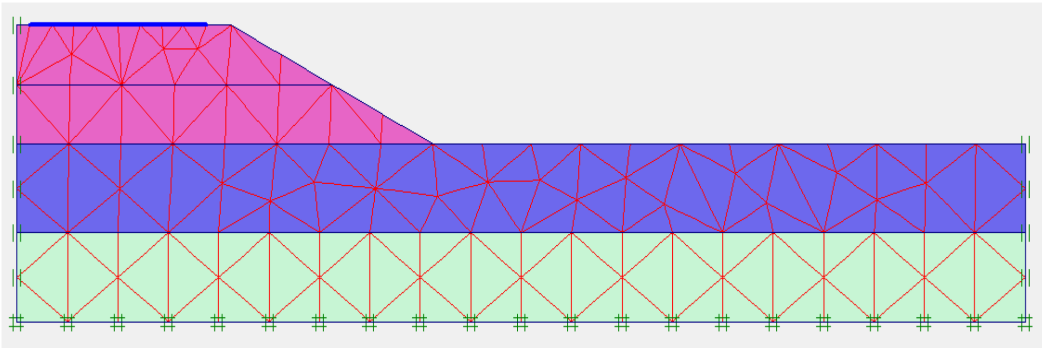

Figure 1 Typical Mesh Generation

The deformation at the base of the soft soil layer is assumed to be zero. Hence the base is fixed in x and y directions. The two vertical boundaries are assumed to be fixed in x direction. The initial conditions include the existence of the phreatic level at a depth of 2 metres below the ground level. It is assumed that water can flow out from all boundaries and excess pore water pressures can dissipate in all directions. However according to the present geometry model, the left vertical boundary must be closed as it is a line of symmetry and not a true boundary.

Material Models

The embankment consisting of different materials and foundation soil comprising of soft clay and well graded sand has been modelled using the Mohr-Coulomb soil model. The embankment section also included 30 cm thick reinforced concrete pavement working platform above the existing ground.

A plate element was used to simulate the pavement layer, which is placed on top of the embankment. The properties of the pavement layer are obtained from the literature and they are entered in a material set as a Young's modulus value of 30 GPa and a thickness of 0.30 m (for road). The material properties of subsoil, pavement layers and embankment materials which are used in the current modeling analysis are listed in TABLES I-IV.

TABLE I Properties of Subsoils used in FE Analysis

Subsoil Properties	**Soft Clay**	**Sand (Well-graded)**	**Unit**
Type of behaviour	Undrained	Drained	-
γ_{unsat}	15	17	kN/ m^3
γ_{sat}	18	20	kN/ m^3
k_x	1E-04	0.5	m/day
k_y	1E-04	0.5	m/day
E_{ref}	1000	30000	kN/ m^2
ν	0.33	0.3	-
c_{ref}	2	1	kN/ m^2
ϕ	24	34	degree
ψ	0	4	degree
Material Model	Mohr-Coulomb (MCM)	Mohr-Coulomb (MCM)	-

TABLE II Pavement properties used in FE Analysis

Pavement Properties	**Concrete**	**Unit**
EA	1.580E+11	kN/m
EI	1.179E+09	kNm^2/m
W	1.8	kN
ν	0.15	-

TABLE III Embankment Material Properties – MCM

Embankment Properties	Normal Fill	Fly Ash	Unit
Type of behaviour	Drained	Undrained	-
γ_{unsat}	16	15.27	kN/ m^3
γ_{sat}	20	16.04	kN/ m^3
k_x	1	0.25	m/day
k_y	1	0.21	m/day
E_{ref}	3000	1747	kN/ m^2
ν	0.30	0.33	-
c_{ref}	1	32	kN/ m^2
ϕ	30	31.62	degree
ψ	0	1.62	degree
Material Model	Mohr-Coulomb (MCM)	Mohr-Coulomb (MCM)	-

TABLE IV Material properties of the Geogrid

Parameter	Name	Geogrid	Unit
Material Model	Model	Elastic	-
Normal Stiffness	EA	50	kN/m

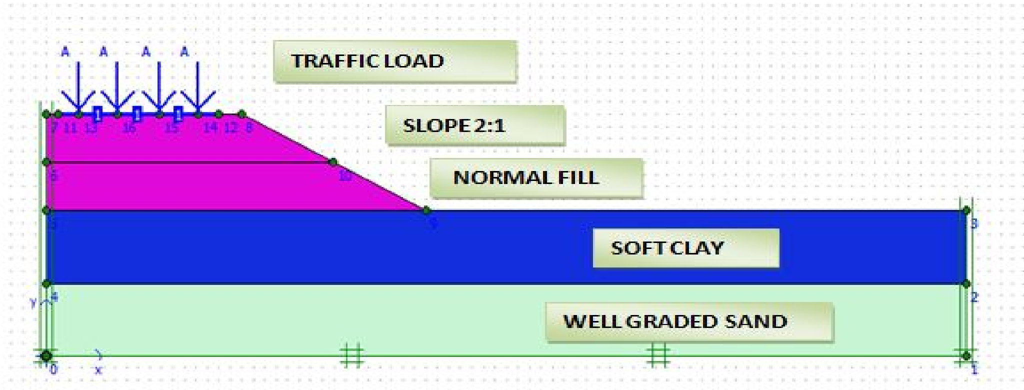

Figure 2 Geometry of normal fill embankment model

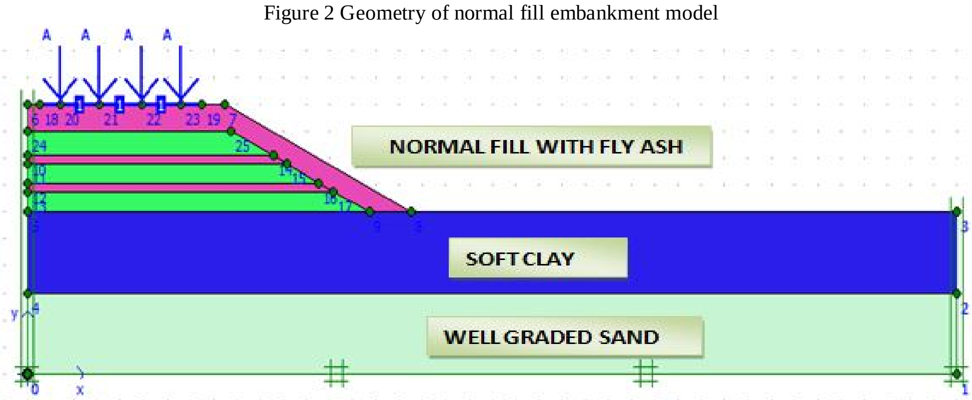

Figure 3 Geometry of fly ash normal fill embankment model

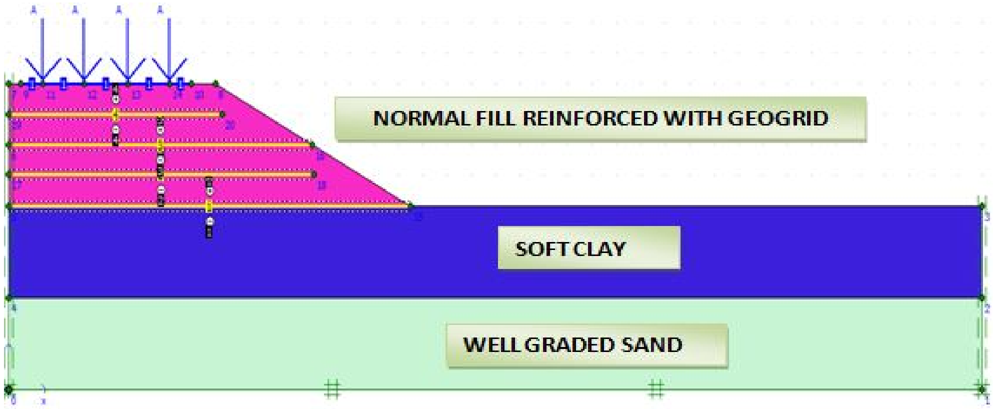

Figure 4 Geometry of normal fill embankment reinforced with geogrid model

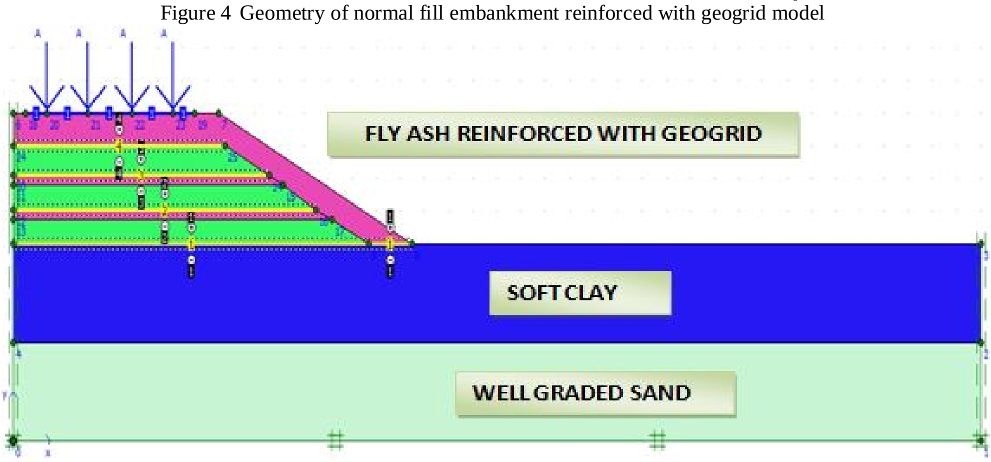

Figure 5 Geometry of geogrid reinforced fly ash embankment model

Initial Conditions and Boundary Conditions

In the initial conditions, water unit In the initial conditions, water unit weight was set to 10 kN/m3. The water pressure is fully hydrostatic and is based on a general phreatic level. In addition to phreatic level, boundary condition for consolidation analysis can be additional input. The lines of consolidation need to be selected in vertical direction that means vertical boundaries must be closed to restrain the horizontal flow and no free outflow is allowed at that boundary. In the analysis, constant ground water level has been considered.

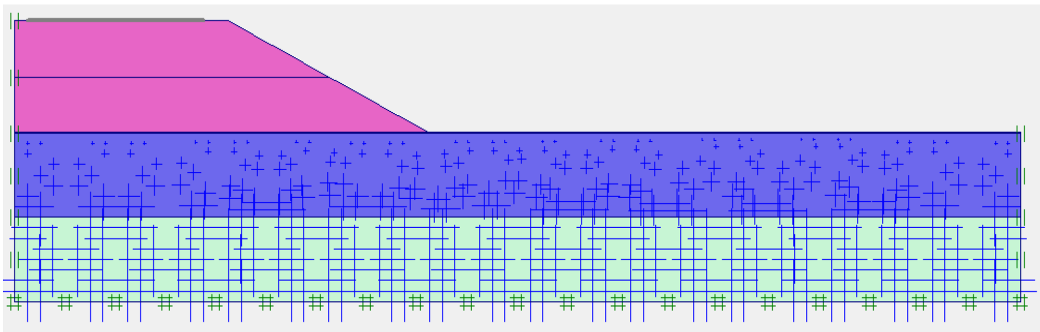

Figure 6 Active Water Level

Initial Stresses

After the generation of water pressures, initial stresses were generated. In the initial situation the embankment is not present therefore it was deactivated first. When using Mohr Coulomb model, the analysis require the generation of the initial stresses by means of K_0 procedure, which was then used to calculate the initial stresses. The suggested K0 procedure is based on Jaky's formula (K_0=1-sinϕ). After the generation of Phreatic level and initial stresses, the input is complete and calculations can be generated.

Calculations

These calculations are generally used to define the different phases of embankment construction. Figure 7 presents a snapshot of different phases of the construction process as implemented in PLAXIS.

The construction sequence was simulated by adding embankment fill in two layers with equal thickness (2 m). Four loads coming in contact with road through tires were used to simulate the traffic loading.

In the modeling analysis, the embankment construction consists of two phases, each taking 30 days. After the construction phase, consolidation period of 60 days was introduced to allow excess pore pressure to dissipate. The consolidation option in FEM software allows fully automatic time stepping procedure that takes the critical time step into account. Pavement construction and traffic loading were also taken into the consolidation analysis with different time intervals. The last phase in consolidation analysis was selecting minimum pore pressure where the default value of 1kN/m2 was used for the pore pressure.

To calculate the global safety factor for the road embankment, the phi-c reduction option was selected and used in the next phase.

Next Insert Delete...

Identification	Phase no.	Start from	Calculation	Loading input	Time	Water
Initial phase	0	0	N/A	N/A	0.00 ...	0
1st stage const	1	0	Consolidation	Staged Construction	30.0...	1
Consol Period	2	1	Consolidation	Staged Construction	60.0...	1
2nd stage const	3	2	Consolidation	Staged Construction	30.0...	3
Consol Period	4	3	Consolidation	Staged Construction	60.0...	3
Pavement Const	5	4	Consolidation	Staged Construction	30.0...	5
Traffic Loading	6	5	Consolidation	Staged Construction	1000...	6
Pore Pressure	7	6	Consolidation	Minimum pore pressure	463....	6
Safety factor pos...	8	1	Phi/c reduction	Incremental multipliers	0.00 ...	1
Safety factor pos...	9	3	Phi/c reduction	Incremental multipliers	0.00 ...	3
Safety factor pos...	10	5	Phi/c reduction	Incremental multipliers	0.00 ...	5
Safety factor pos...	11	6	Phi/c reduction	Incremental multipliers	0.00 ...	6
Safety factor pos...	12	7	Phi/c reduction	Incremental multipliers	0.00 ...	6

Figure 7 Calculation Steps using PLAXIS

II. RESULTS AND DISCUSSIONS

Vertical Settlement

On evaluating the total settlement, it was seen that the failure mechanism is developing with excess pore pressure distribution. The settlement at the pavement surface and embankment were increasing considerably after the end of the construction of embankment and pavement. This is due to the dissipation of excess pore pressure in soft soil layer which causes consolidation in soils. From figure 8 & 9, it can be noticed that in case of fly ash fill reinforced with geogrid, maximum horizontal and vertical settlement has been found to be 0.12 mm and 1.67 mm respectively which is least compared to other embankment fill materials. This is expected as geogrid, one of the widely used geosynthetics; effectively used owing to high strength properties and its better performance in reducing settlement problems in soft soil. In addition, the fly ash has low unit weight than normal soil and high strength properties which helps in reducing settlements in soft soils.

Vertical Stresses

It is observed that more stress concentration occurs at bottom of the normal fill as the loads are transmitted from the top to the bottom. The degree of stress concentration is reduced when fly ash is used in place of normal fill due to its low unit weight and high strength properties.

From figures 8 and 9, it is observed that stresses are found to be decreasing with the use of different embankment materials. However in case of normal soil reinforced with geogrid stresses generated in soft soil is observed to be least.

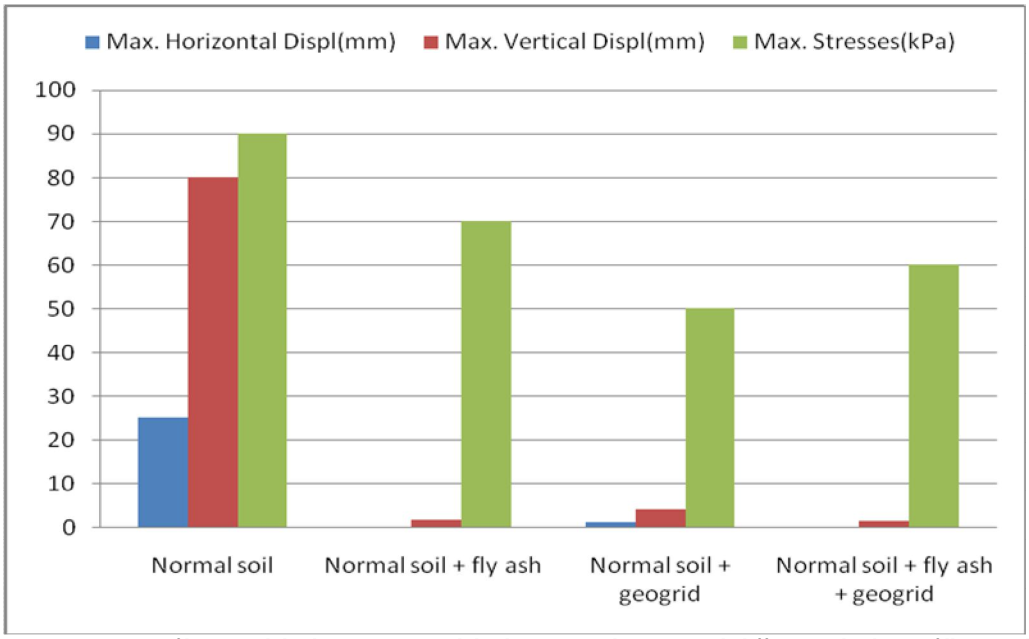

Figure 8 Variation of horizontal displacement, vertical displacement and stresses with different embankment fill materials

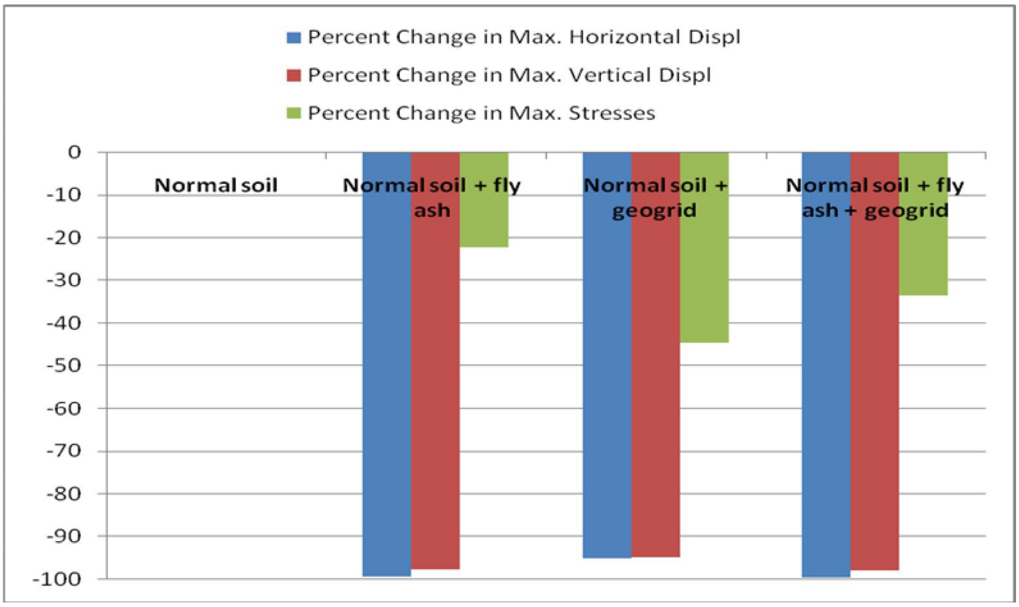

Figure 9 Variation of % change in horizontal displacement, vertical displacement and stresses for different embankment fill materials

Results of Safety factor Analysis

Following table shows comparison of factor of safety values computed from phi/c-reduction calculation option available in PLAXIS for the different embankment fill materials.

TABLE V Factor of Safety values for different Embankment fill materials

Type of Embankment	**Factor of Safety**
Normal soil	1.406
Normal soil with fly ash fills	1.432
Normal soil reinforced with geogrid	1.715
Normal soil with fly ash fills and reinforced with geogrid	1.442

It can be observed from the above table that normal soil reinforced with geogrid performs better compared to other materials.

III. CONCLUSIONS

- The least value of maximum horizontal displacement was found to be in fly ash fill reinforced with geogrid embankment viz. 0.12 mm resulting in 99.42% decrement from normal soil embankment (25 mm).
- The least value of maximum vertical displacement in fly ash fill reinforced with geogrid embankment was found to be 1.67 mm resulting in 97.91% decrement from normal soil embankment (80 mm).
- The maximum % reduction in stresses was observed in normal soil fill reinforced with geogrid embankment viz. 44.44%.
- The maximum FOS against slope failure was observed in case of normal soil fill reinforced with geogrid embankment (1.715)

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