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FINITE ELEMENT ANALYSIS OF GEOGRID REINFORCED EMBANKMENT FOR HIGHWAYS

Mrs. Richa shahi[1] Mr. Manas Rathore[2]
Research Scholar[1] Assistant Professor[2]
Department of Civil Engineering, Kalinga University, Naya Raipur (C.G.)[1 2]
richashahi12@gmail.com[1] manas.rathore@kalingauniversity.ac.in[2]

ABSTRACT

Geo synthetics are commonly used for reinforcement of embankments and retaining structures. They score over the traditional methods in terms of effectiveness, cost and speed of construction. The mechanism of geogrid reinforced embankment is to provide a stable force at the soil-geogrid as a result of the interlock and friction action between the layer particles and grid, and to provide membrane reinforcement. Several studies have been conducted to analyze the performance to geogrid reinforced embankment supporting road or rail infrastructure but the interface interaction between the geogrid with embankment soil and between the pavement and the embankment fill is not considered comprehensively in the existing literature. The time dependence of geogrid reinforcement properties is also not considered. Further optimum geogrid spacing of geogrid as a function of embankment height and slope also, needs to be examined. The aim of this study the impact of these factors on the stability and performance on the embankment using numerical analysis tools. The results of the study are graphically represented in form of total and differential settlements, displacement and stress contours and strain developed in the geogrid reinforcement.

Keywords: Embankments and Retaining structures, Geo synthetics, Geogrid, Finite element analysis

INTRODUCTION

With the rapid advance in transportation infrastructure network, there is increasing need for more high-speed railways, highways and expressways. Often such constructions are required in hilly areas which requires comparatively higher and steeper embankments. Owing to the land-use restriction and limited transportation conditions, geosynthetic-reinforced soil (GRS) embankments are widely adopted. They offer the additional advantages of high construction efficiency, low costs, good serviceability, and seismic performance (Rowe and Ho, 1998; Ferreira et al., 2016; Holtz, 2017). It has been well established that the soil can resist compression and shear loads but is not stable when tensile force is applied on it. There is enough empirical evidence to suggest that settlement, slope stability and soil bearing capacity are all challenges to construction of embankment. (Mamat et. al 2019). In the event of widening of pavement, the anticipated no uniform settlements and developed shear stresses result in cracks in the pavement along the joint between the existing and freshly constructed pavements (Ludlow et. al 1993). The occurrence of this phenomenon can be attributed to one or more of the following causes. The proposed three possible failure mechanisms in road widening include: (1) shear cracking caused by embankment slippage; (2) bottom-up cracking caused by vehicle load; and (3) top-down cracking caused by no uniform deformation., preloading, light weight embankment, cement deep mixing pile, and separating walls, have been used to reduce the increase the stability of embankment on soft ground (Deschamps et. al 1999). Out of these treatment methods, the geosynthetic reinforcement (geogrid or geotextile) is usually incorporated at the subgrade-ground interface to reinforce the embankment on soft subgrade layers. Geosynthetics are commonly used for reinforcement of embankments and retaining structures [13,14]. They score over the traditional methods in terms of effectiveness, cost and speed of construction. The mechanism of geogrid reinforced embankment is to provide a stable force at the soil-geogrid interface as a result of the interlock and friction action between the layer particles and grid, and to provide membrane reinforcement. Thus, the reinforcement can better distribute the applied load over a larger area and compensate for the lack of tensile strength within surrounding soils.[15,16] Many successful cases have been achieved in the strengthening of soft soil foundation with geosynthetic reinforcement to facilitate the construction process, extend the service life, reduce the necessary fill thickness, diminish the deformation.[17,18]

NUMERICAL METHODS

Numerical methods can be employed for the analysis of geogrid reinforced soil (Hatami and Bathurst, 2005; Mehdipour et al., 2013; Hussein and Meguid, 2016) Numerical simulation is a convenient and economical approach to get insights into the behaviour of high and steep embankment, reinforced or otherwise. [19,20] The results, however need to be validated using carefully designed experimentation. Numerically methods can be generally classified as:

(a) Finite Element method (PLAXIS) (b) Finite Difference method (FLAC)

RESEARCH GAPS

Based on the literature study the key areas that need further analysis were identified.

1. Interface interaction of geogrid-embankment material and interface modelling of pavement -embankment fill is not considered comprehensively in the existing literature. The model is highly sensitive to the parameters used for interface normal and shear stiffness and the material model properties.
2. The non-linearity of soil both in terms of geometric and material are not provided in detail in the existing literature.
3. The time dependence of geogrid reinforcement properties is also not considered.
4. Optimum geogrid spacing as a function of embankment height and slope needs to be examined.

OBJECTIVES

The objective of this study is to study and analyze the performance of embankment as it is built and to

1. Design the optimum tensile strength and spacing of geogrid to be used in embankment as ground improvement technique to enhance the stability of embankment and then.
2. Determining the impact of soil reinforcement on factor of safety of embankment
3. Effect of interface parameters
4. Study the impact of material non-linearity.

MATERIAL MODELS

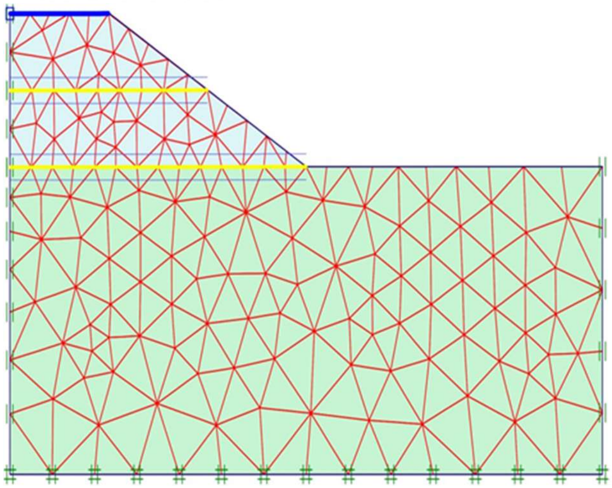
The embankment consisting of different materials and foundation soil comprising of soft clay and well graded sand has been modelled using the Mohr-Coulomb soil model considering both linear and non-linear elasticity [21,22]. The embankment section also included thick reinforced concrete pavement working platform above the existing ground. A plate element was used to simulate the pavement layer, which is placed on top of the embankment [23,24]. 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. Traffic load is simulated using uniformly distributed load. [25,26]

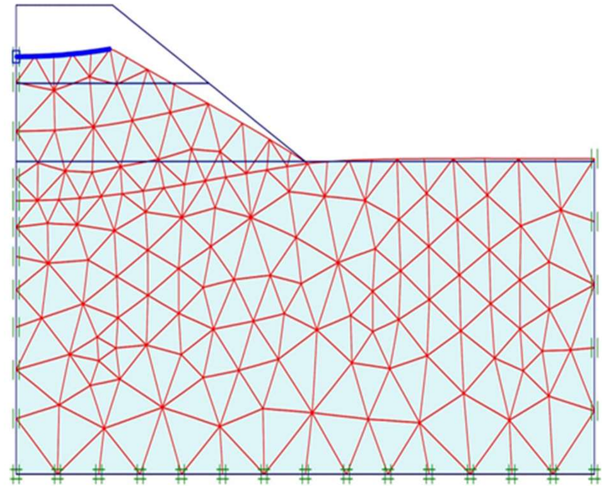
Subsoil Properties	Soft Clay	Sand (Well Drained)	Unit
Type of Behaviour	Undrained	Drained	
γunsat	17	18	kN/m^3
γsat	19	18	kN/m^3
k_x	1E-2	1	m/day
k_y	1E-2	1	m/day
Eref	17	18	kN/m^3
ν	0.3	0.3	kN/m^3
cref	5	0.1	kN/m^2
φ	25	35	degrees
ψ	0	6	degrees
Material Model	Mohr Coulomb	Mohr Coulomb	

For hardening soil model the values from Mohr-Coulomb model results are back fitted to make the comparison reasonable. Geogrids are placed at the base of the embankment and at mid height (2.5 m) , Material model = Linear elastic with no failure limit. Normal stiffness, EA = 50 kN/m

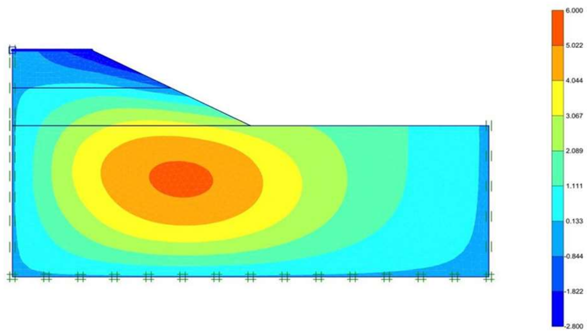
Identification	Start from	Calculation	Loading Input
Initial Phase	NA	NA	NA
Phase 1	Initial Phase	Consolidation	Staged Construction
Phase 2	Phase 1	Consolidation	Staged Construction
Phase 3	Phase 2	Consolidation	Staged Construction
Phase 4	Phase 3	Consolidation	Staged Construction
Phase 5	Phase 4	Consolidation	Staged Construction
Phase 6	Phase 5	Consolidation	Staged Construction
Phase 7	Phase 6	Consolidation	Minimum Pore Pressure

Table: Construction stages





Schematic and FE Mesh Results for Mohr Coulom Model
(Deformed Mesh)



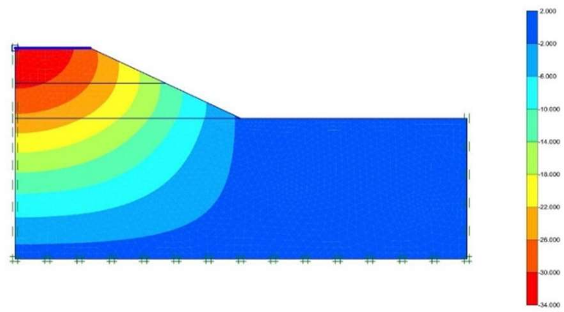
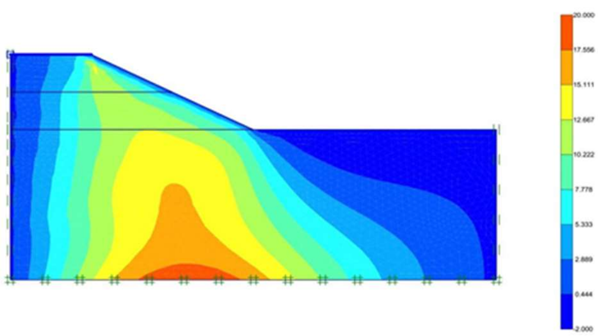


Fig Ux (mm) Fig Uy (mm)



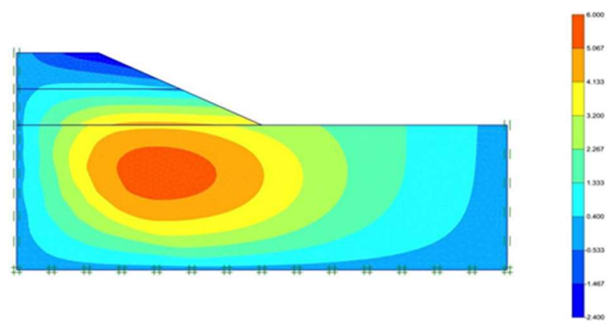


Fig. $\boldsymbol{\sigma xy'}$(kPa) Results For Mohr Coulomb model with
Geogrid Ux (mm)

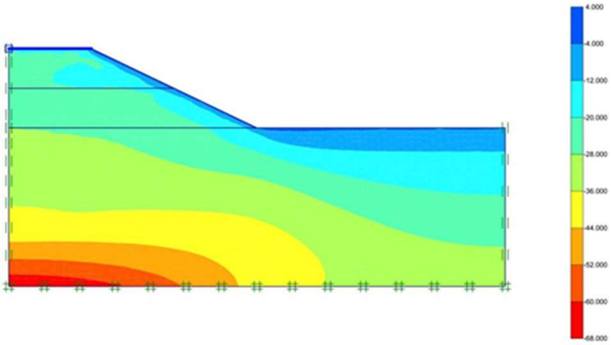


Fig. $\boldsymbol{\sigma x'}$ (kPa)

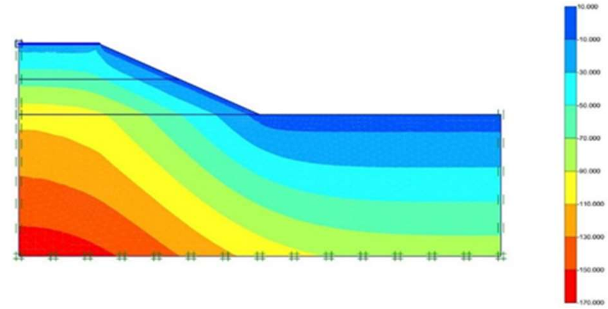


Fig. $\boldsymbol{\sigma y'}$ (kPa)

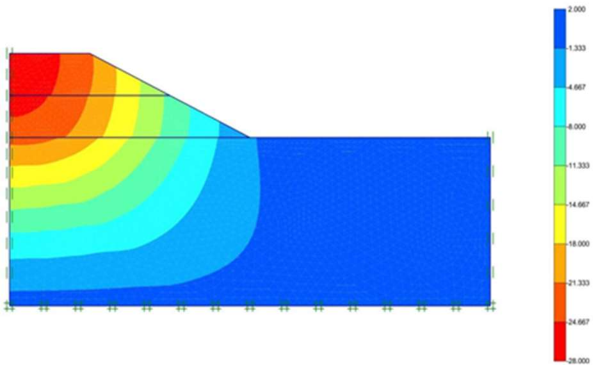
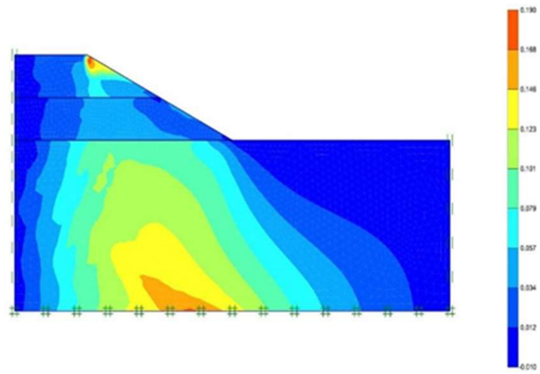


Fig Uy (mm)



Shear strain (%)

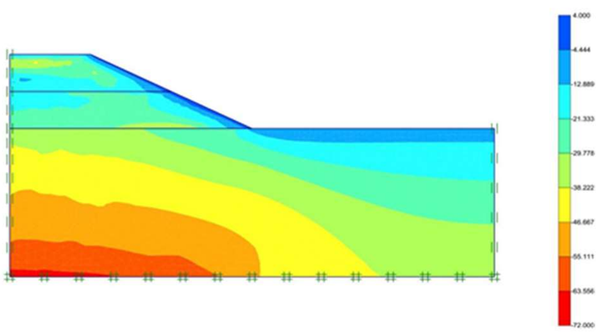


Fig. $\boldsymbol{\sigma x'}$(kPa)

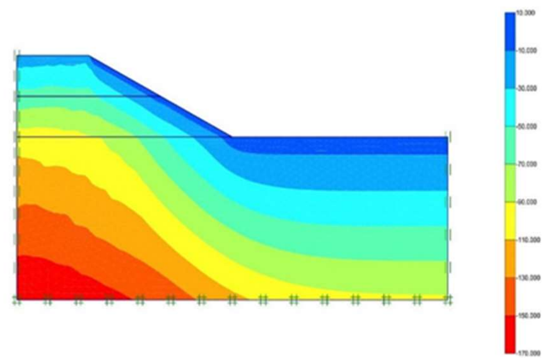


Fig. $\boldsymbol{\sigma y'}$(kPa)

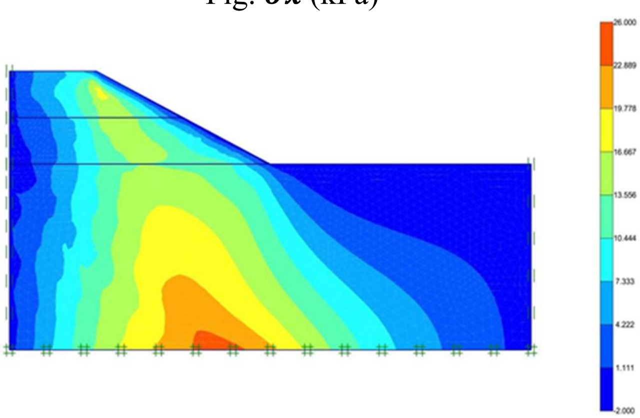
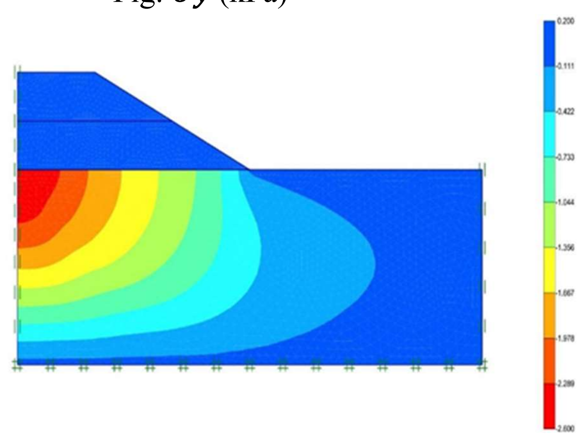
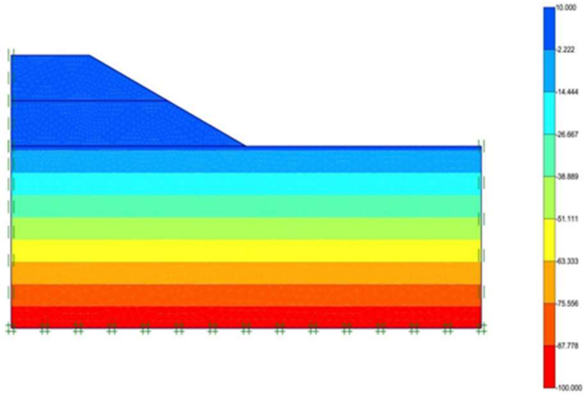


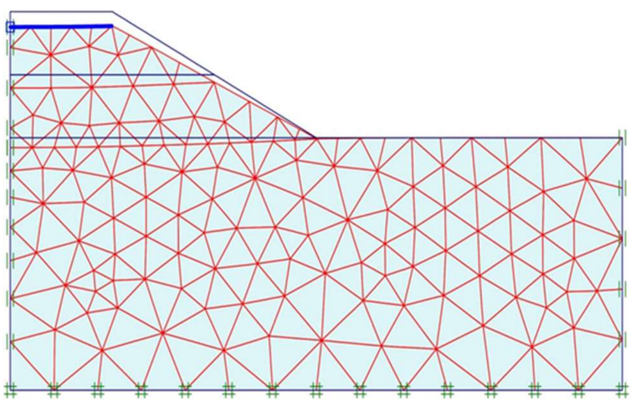
Fig. $\boldsymbol{\sigma xy'}$ (kPa)

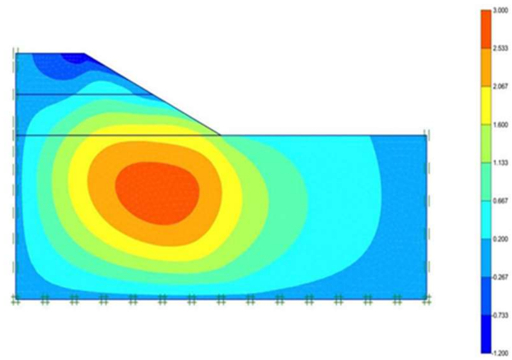


Excess PP (10^-3)

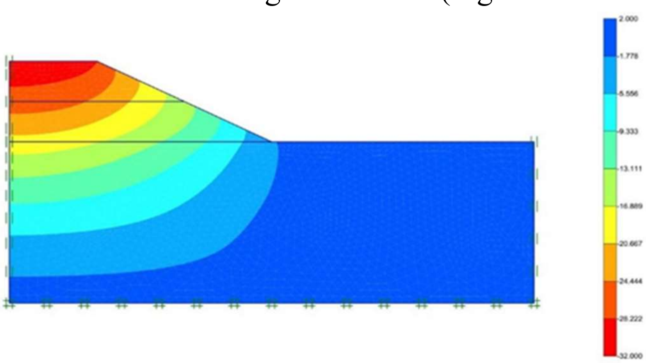


Active PP (KpA)





Results for Hardening Soil Model (Fig. Deformed mesh (Scale 1:20)) Fig. Ux (mm)



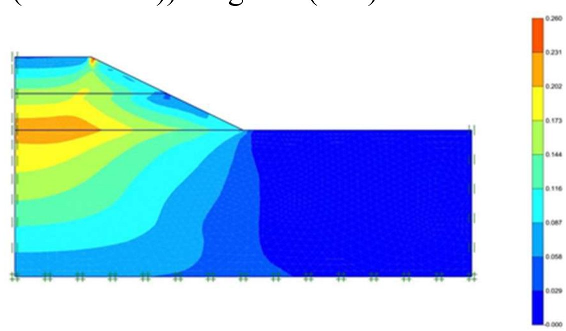
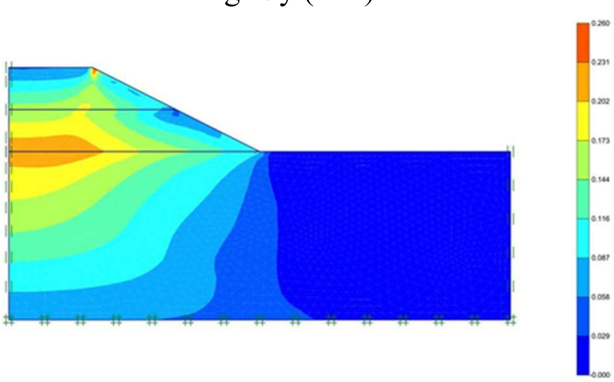


Fig. Uy (mm) Fig. Shear strain (%)



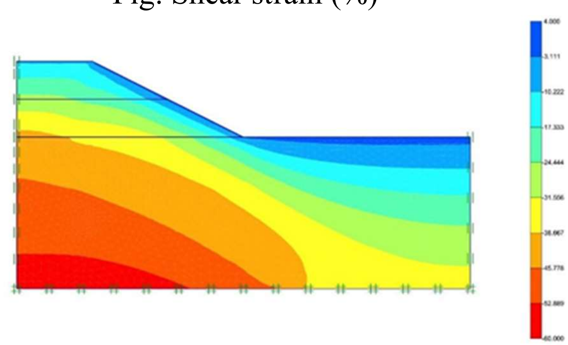


Fig. Shear strain (%) Fig. $\sigma x'$(kPa)

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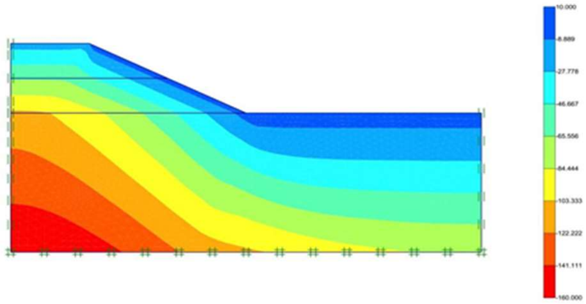


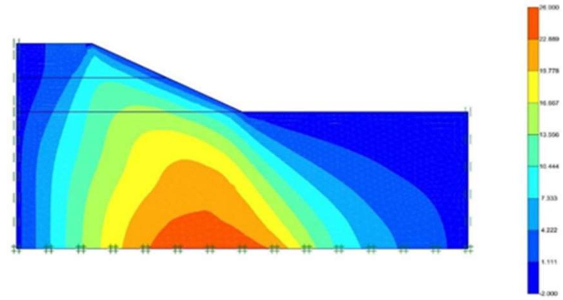
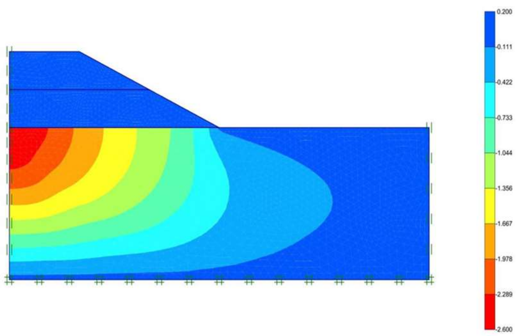
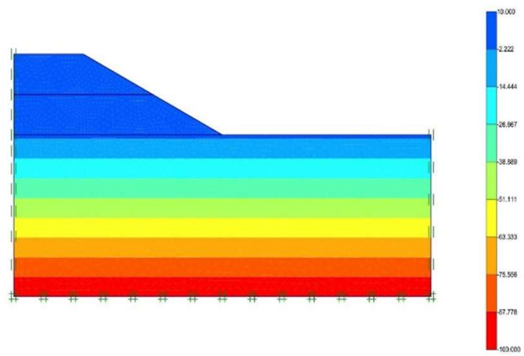


Fig. $\sigma y'$ (kPa)

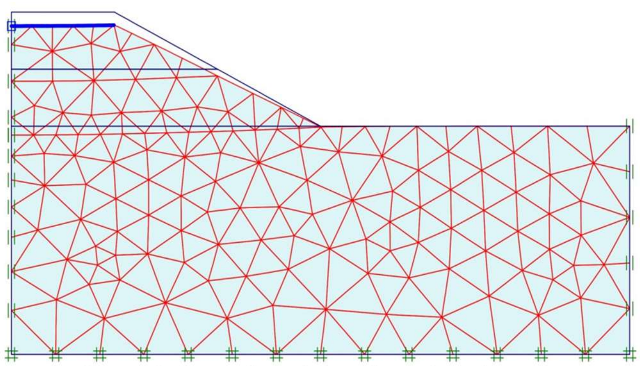
Fig. $\sigma xy'$ (kPa)

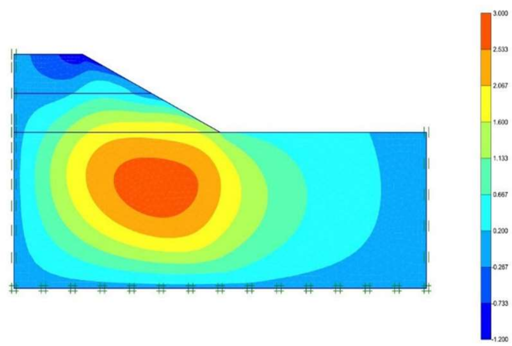




Excess PP (10^-3)

Active PP (KpA)





Results for Hardening Soil Model (Deformed mesh (Scale 1:20)

Fig. Ux (mm)

Fig. Uy (mm)

Fig. Shear strain (%)

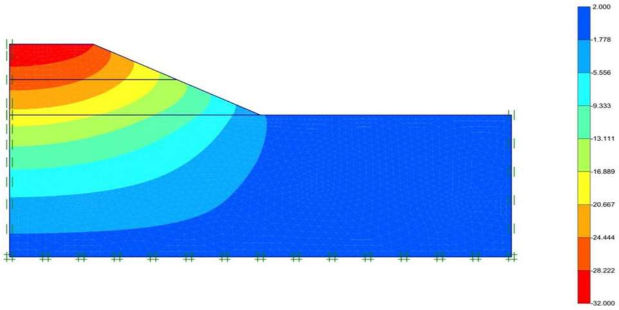


Fig. Uy (mm)

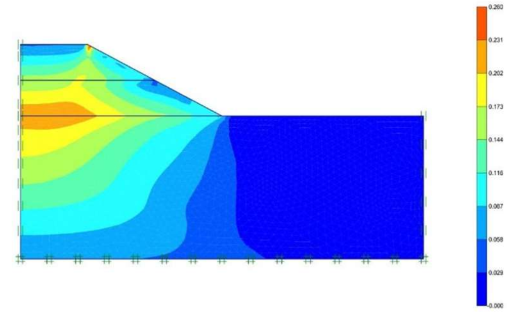


Fig. Shear strain (%)

Fig. $\boldsymbol{\sigma x'}$ (kPa)

Fig. $\boldsymbol{\sigma y'}$(kPa)

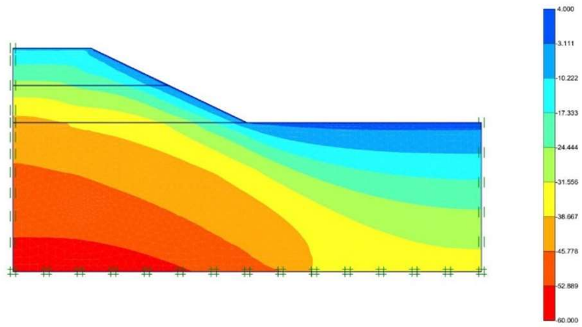
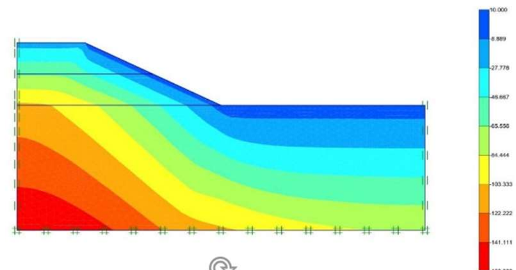
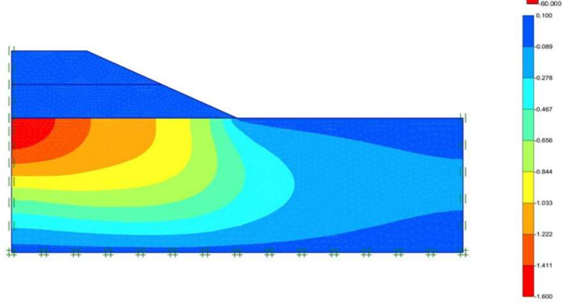


Fig. $\boldsymbol{\sigma_x'}$





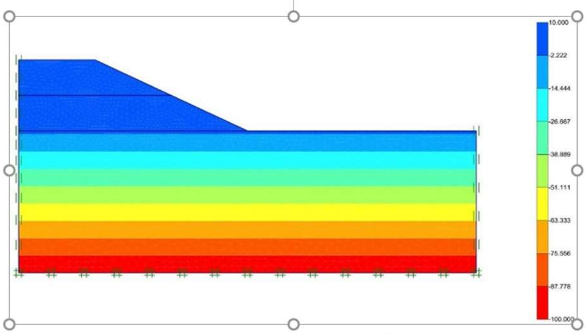
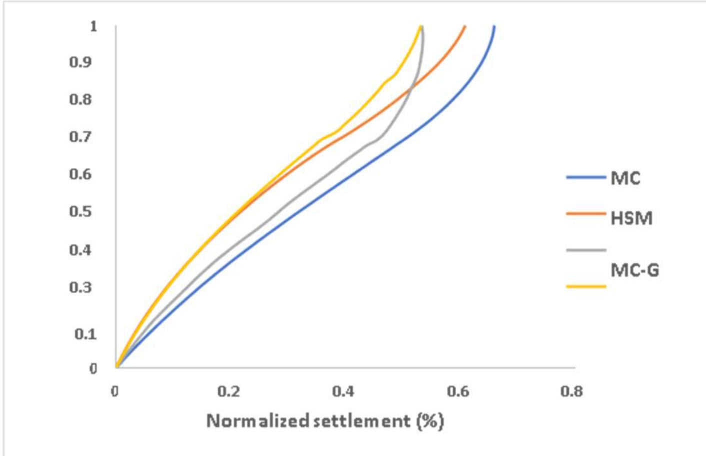


Fig. Excess PP (10^{-3} kPa)

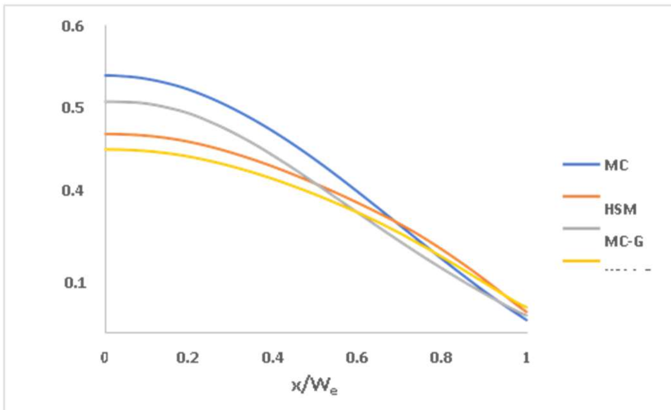
Fig. Active PP (10^{-3} kPa)

Stages	MC	HSM G	HSM
8	1.475	1.538	1.438
9	1.478	1.471	1.444
10	1.468	1.47	1.443
11	1.476	1.471	1.44
12	1.471	1.464	1.445

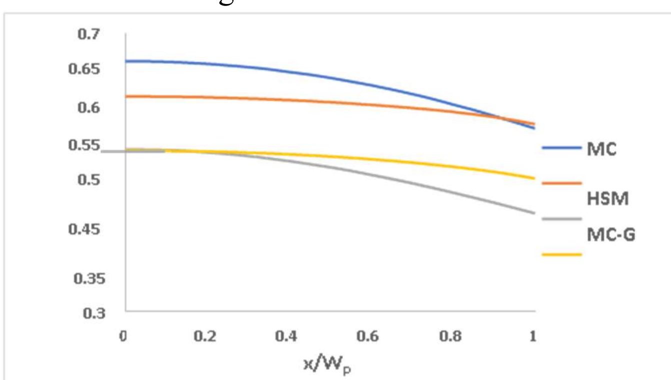
Table for Comparison of safety factors



Vertical Settlement at section passing through the Centre of pavement.



Settlement along the width of embankment at base



Settlement of the pavement

x= Distance from the center of embankment measured horizontally, WP =width of pavement in model, 5 m (half of the actual width), We = width of the embankment in model at base, 15 m (half of actual width), Normalized settlement = settlement normalized with depth of embankment (5 m).

			HSM G	HSM	MCG	MC
Pavement		Max. SF (kN/m)	0.99	1.01	1.15	1.78
		Max. BM (kN/m)	1.44	1.22	3.79	3.53
		Max AF(kN/m)	3.51	4.67	25.7	13.55
		Uy,max (mm)	26.55	30.43	26.64	32.96
Geogrid	2	Max AF(kN/m)	0.156	-	0.36	-
		Uy,max (mm)	23.61	-	25.97	-
	1	Max AF(kN/m)	0.22	-	1.02	-
		Uy,max (mm)	18.16	-	22.85	-
Soil		Uy,max	26.55	30.43	26.73	32.96
		edge	2.5	2.1	1.7	1.3
		center	17.2	19.4	22.7	25.1

Abbreviations

MC – Mohr Coulomb, MC-G -Mohr Coulomb with geogrid HSM – Hardening soil model HSM-G Hardening soil model with geogrid SF – Shear force, BM – Bending moment AF – Axial force

Results

According to Indraratna et al. (1992), the ratio of lateral displacement–settlement is a good indicator of embankment stability. The ratio of lateral displacement–settlement is defined as the ratio of the maximum lateral displacement at the toe to the maximum settlement at the center line of an embankment. The result of the proposed analysis shall include the following feature.

1. Factor of safety analysis to get a general idea of the slope stability.
2. Lateral Displacement at the embankment face.
3. Total settlement measured at the Centre of the embankment.
4. Differential settlements at the crest points in the embankment.
5. Settlement per layer.
6. Displacement profiles (vertical and horizontal).
7. Stress field contours are plotted for Vertical and Horizontal stresses.
8. Strains in geogrid reinforcement

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