Stabilization of Fly Ash Slope Using Plastic Recycled Polymer and Finite Element Analysis Using Plaxis 3D

Tushar Vasant Salunkhe, Sariput M. Nawghare, Maheboobsab B. Nadaf, Sushovan Dutta, J. N. Mandal

***Abstract*—**The model tests were conducted in the laboratory without and with Plastic recycled polymer in fly ash steep slopes overlaying soft foundation soils like fly ash and powai soil in order to check the stability of steep slope. In this experiment, fly ash is used as a filling material and Plastic Recycled Polymers of diameter = 3mm and length = 4mm were made from waste plastic product (lower grade plastic product). The properties of fly ash and Plastic recycled polymers are determined. From the experiments, load and settlement have measured. From these data, load –settlement curves have reported. It has been observed from test results that load carrying capacity of mixture fly ash with Plastic Recycled Polymers slope is more than that of fly ash slope. The deformation of Plastic Recycled Polymers slope is slightly more than that of fly ash slope. A Finite Element Method (F.E.M.) was also evaluated using PLAXIS 3D version. The failure pattern, deformations and factor of safety are reported based on analytical programme. The results from experimental data and analytical programme are compared and reported.

***Keywords*—**Fly ash, Plastic recycled polymer, Factor of safety, Finite element method (FEM), Bishop's simplified method.

I. Introduction

THE plastic recycled polymer made up of waste lower grade plastic product which cannot be recycled. The dimension of Plastic recycled polymer having its length 4 mm and diameter 3 mm were used in present study. The series of interlocking cells are filled with fly ash collected from thermal power plant from Mumbai. The circular geocell confine the fly ash within its pocket. Many authors such as [1]-[5] reported on Behavior of fly ash at different mix ratios with plastic recycled polymers, [6]-[8] and [7] have used metallic and cellular reinforcement for reinforced soil walls and slopes. Here a model test with waste plastic polymers was used for the construction of steep slopes using waste fly ash. Experimental investigation by Bishop's Simplified method [9] and finite element analysis Plaxis 3D [10] were reported.

II. Properties of Fly Ash and Plastic Recycled Polymer

The properties of the fly ash are: specific gravity = 2.18, D_{60}=0.045mm, D_{30}=0.014mm, D_{10}=0.003mm, coefficient of uniformity (C_u) =15, coefficient of curvature (C_c) =1.45, cohesion = 0.03kN/m^2, angle of internal friction=20^0, optimum moisture content = 18.6% and maximum dry unit weight =12.21 kN/m^3 and corresponding mixture of fly ash with Plastic recycled polymer dry unit weight =13.30kN/m^3 [5].The properties of Plastic recycled polymer: specific gravity = 2.154 and Density=0.62g/cc. Direct shear test were conducted on fly ash samples with a degree of compaction equal to 90% and maximum dry unit weight of fly ash with three different normal pressure 50 kPa, 100 kPa and 150kPa to evaluate the peak angle of internal friction (Φ). The dilation angle of fly ash was calculated from direct shear test data by measuring the maximum upward angle of the curve from relationship between vertical displacements to horizontal displacement. The properties used in the finite element simulation are given in Table I.

III. Model Test Setup

The model test tank used in this study was fabricated at Geosynthetics Research and Testing Laboratory at IIT Bombay and the dimensions of the test tank are as follows: length = 70 cm, width = 40cm and height = 50 cm. The photograph is shown in Fig. 1. Test was performed in the laboratory without and with plastic recycled polymer. One side of the model setup was covered with Perspex sheet to observe the failure pattern.

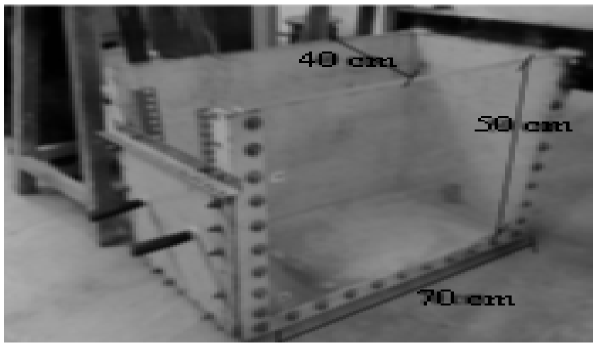


Fig. 1 Test set up

Schematics of the slope models in the present study are shown in Fig. 2. The procedure adopted is in the following manner.

- Model1 and Model2: Fly ash foundation bed was prepared of length = 70 cm, width= 40 cm and depth= 10 cm.
- Model3 and Model4: Powai soil foundation bed was prepared of length = 70 cm, width= 40 cm and depth= 10 cm.

Tushar Vasant Salunkhe was with the Indian Institute of Technology, Bombay, Mumbai, Maharashtra, India (corresponding author to provide phone: +91-916-746-3827; e-mail: maheboob_nadaf@iitb.ac.in).

Sariput M. Nawghare, Maheboobsab B. Nadaf, Sushovan Dutta, and J. N. Mandal are with the Indian Institute of Technology, Bombay, Mumbai, Maharashtra, India (e-mail: sariputcr@gmail.com, maheboob_nadaf@iitb.ac.in, sushovan@iitb.ac.in, cejnm@civil.iitb.ac.in).

- For Model1 and Model3, fly ash slope height = 30cm was prepared over the foundation bed at a slope angle of 60°.For Model2 and Model4, the slope was made of mix of fly ash and Plastic Recycled polymer (PRP).
- The fly ash was compacted at 18.6% on dry side of optimum moisture content. The fly ash was compacted using modified proctor hammer in subsequent layer of 7.5 cm.
- When entire compaction was over, the incremental load was applied through hydraulic jack on the plate of size 35cm x 10cm placed at the distance of 5.0 cm from the edge of the slope.
- For uniformly distributed loading condition, steel plate of thickness 0.8 cm having its length 30 cm and width 36cm was used.

TABLE I
PROPERTIES USED IN THE FINITE ELEMENT SIMULATION

Model Material	Property	Unit	Value
Fly ash	Dry unit Weight	kN/m^3	12.20
	Young's Modulus (E)	kN/m^2	4200
	Poisson's ration (μ)	-	0.27
	Cohesion (c)	kN/m^2	0.04
	Angle of Internal friction (Φ)	(^{0})	20.04
	Dilation Angle (ψ)	(^{0})	4
Fly ash with Plastic Recycled polymer (50%)	Dry unit Weight	kN/m^3	13.38
	Young's Modulus (E))	kN/m^2	5200
	Poisson's ration (μ)	-	0.32
	Cohesion (C)	kN/m^2	0.17
	Angle of Internal friction (Φ)	(^{0})	39
	Dilation Angle (ψ)	(^{0})	4
Powai Soil	Dry unit Weight	kN/m^3	18.7
	Young's Modulus (E)	kN/m^2	4900
	Poisson's ration (μ)	-	0. 29
	Cohesion (C)	kN/m^2	0.478
	Angle of Internal friction (Φ)	(^{0})	33.4
	Dilation Angle (ψ)	(^{0})	6

IV. SLOPE MODEL UNDER UNIFORMLY DISTRIBUTED LOADING (UDL)

Model 1: Unreinforced Fly Ash Slope Overlaying Fly Ash Bed

The fly ash slope was prepared at the wet of optimum moisture content and compacted by Standard proctor hammer to achieve the required density. The Slope model was having slope angle 60^0 with slope height 30 cm and fly ash bed was of thickness 10 cm. Three trials were considered before the model tests.

The factor of safety is calculated for the observed failure surface using Bishop's simplified method (9) analysis for different surcharge like uniformly distributed load and Strip load. This fly ash slope was monitored under a Uniformly Distributed Load of27.36 kN/m^2. Unreinforced fly ash slope and the observed failure pattern are shown in Fig. 3.

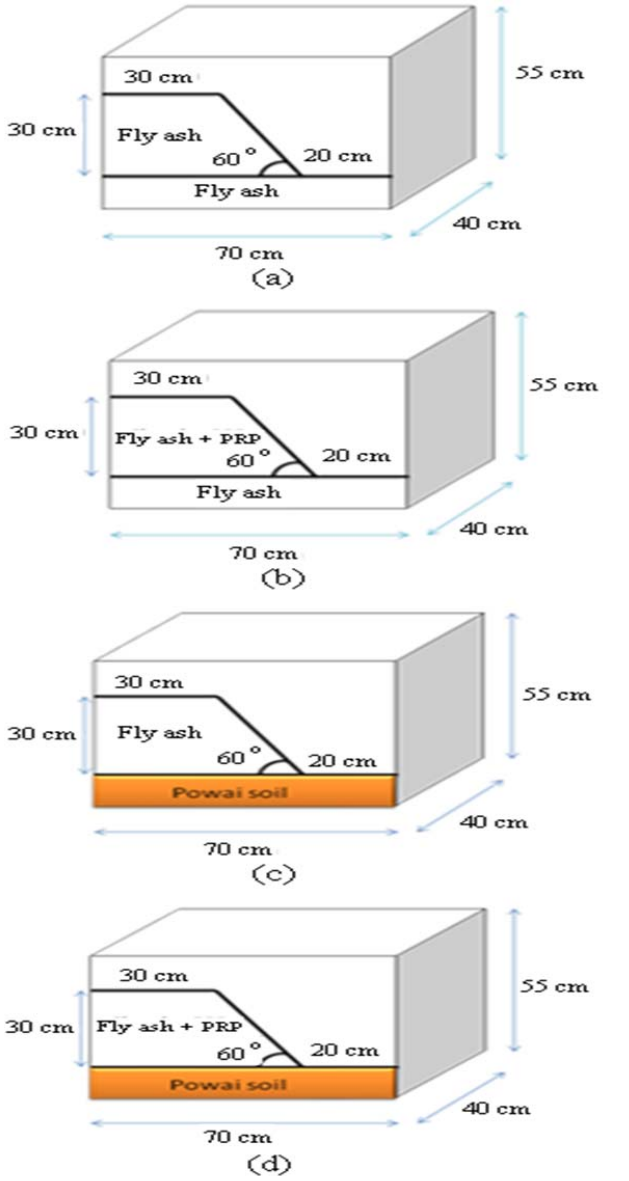
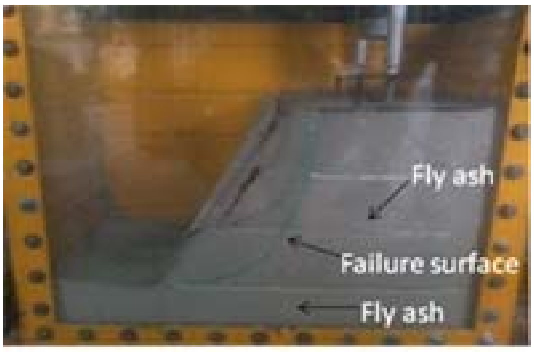


Fig. 2 (a) Model 1: Fly ash slope overlaying fly ash bed (b) Model 2: Fly ash slope with Plastic Recycled polymer overlaying fly ash bed(c) Model 3: Fly ash slope overlaying Powai Soil (d) Model 4: Fly ash slope with Plastic recycled polymer overlaying Powai Soil

(a)



(b)

Fig. 3 (a) Unreinforced Fly ash slope overlaying fly ash bed before failure (b) Unreinforced Fly ash slope overlaying fly ash bed after failure (Model-1)

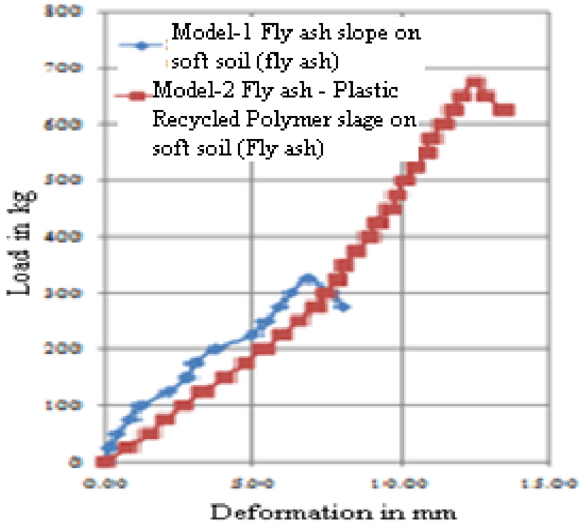
Load at failure of slope (peak load) = 325kg
Total deformation = 6.85 mm
From Bishop's Simplified method analysis:
FOS = 0.975

Model 2: Fly Ash Slope with Plastic Recycled Polymer (PRP) Slope Overlaying Fly Ash Bed

The Recycled Plastic Polymers (PRP) cylindrical in shape of length 0.4 cm and diameter 0.298 cm is made by Scrap plastic material which is already recycled into a different plastic product. Optimum percentage (50%) of Plastic Recycled polymer mixed together with fly ash was used in the model test. The slope model was having slope angle of 60^0 with slope height 30cm. Three trials were considered for fly ash with Plastic Recycled Polymer slope. This fly ash Slope was monitored under a uniformly distributed load of 56.82 kN/m^2. Fly ash slope with Plastic recycled polymer (PRP) overlaying fly ash bed before failure and after failure are shown in Figs. 4 (a) and (b) respectively.

(a)

(b)



(c)

Fig. 4 (a) Fly ash slope with Plastic Recycled Polymer overlaying fly ash bed before failure (b) Fly ash slope with Plastic Recycled Polymer overlaying fly ash bed after failure (c) Load vs Deformation for unreinforced fly ash slope and fly ash with PRP Slope overlaying fly ash bed (Model -2)

Model 3: Unreinforced Fly Ash Slope Overlaying Powai Soil

The fly ash slope was prepared at the wet of optimum moisture content and compacted by Standard proctor hammer to achieve the required density. The Slope model having slope angleof60^0 with height 30 cm and base of foundation soil (Powai Soil) of 10 cm thick. The three trials are considered for this fly ash slope model test. The factor of safety is calculated for the observed failure surface using Bishop's simplified method analysis for different surcharge like uniformly distributed load and Strip load. This fly ash Slope is monitored under a Uniformly Distributed Load of 44.19 kN/m^2. The unreinforced fly ash slope and the observed failure pattern are shown in Fig. 5.

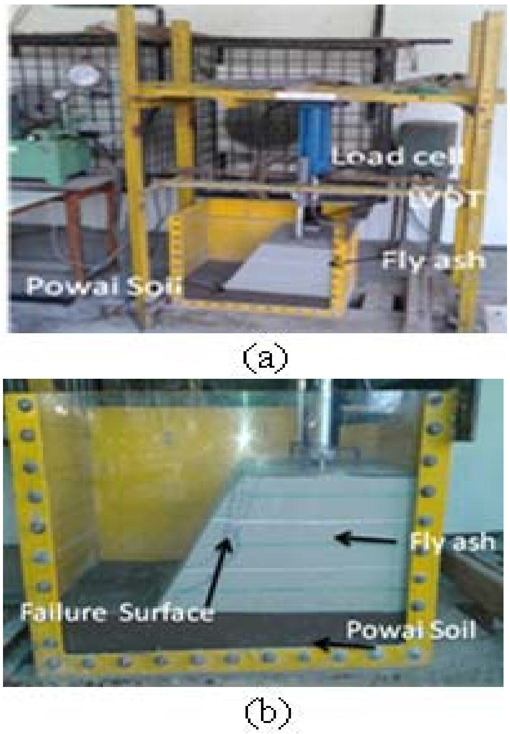


Fig. 5 (a) Unreinforced Fly ash slope overlaying Powai soil before failure (b) Unreinforced Fly ash slope overlaying Powai soil after failure(Model -3)

From Fig. 4 (c):
Load at failure of slope (peak load) = 525kg
Total deformation = 5.20 mm
From Bishop's Simplified method analysis: FOS = 0.640

Model 4: Fly Ash Slope with Plastic Recycled Polymer Overlaying Powai Soil: Uniformely Distributed Loading (UDL)

The Recycled Plastic Polymers are cylindrical in shape of length 0.4 cm and diameter 0.298 cm is made by Scrap plastic material which is already recycled into a different plastic product. For this slope model test the optimum percentage (50%) of Plastic Recycled polymer with fly ash was used to conduct this model test. The slope model is having slope angle of 60º with slope height 30 cm. Three trials are considered for fly ash with Plastic Recycled Polymer slope. This fly ash Slope is monitor under a Uniformly Distributed Load of 82.07 kN/m^2. Fly ash with Plastic recycled polymer (PRP) slope and the observed failure pattern is shown in Fig. 6.

From Fig. 7:
Load at failure of slope (peak load) = 975kg
Total deformation = 19.68 mm
From Bishop's Simplified method analysis: FOS = 2.290

The load versus deformation of given model for fly ash slope and fly ash with plastic recycled polymer slope under uniformly distributed loading is shown in Fig. 7.

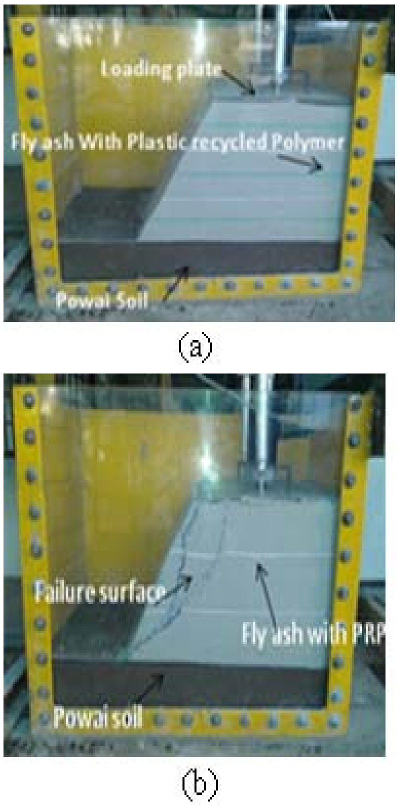


Fig. 6 (a) Fly ash slope with Plastic Recycled Polymer overlaying powai soil before failure (b) Fly ash slope with Plastic Recycled Polymer overlaying fly ash bed after failure (Model -4)

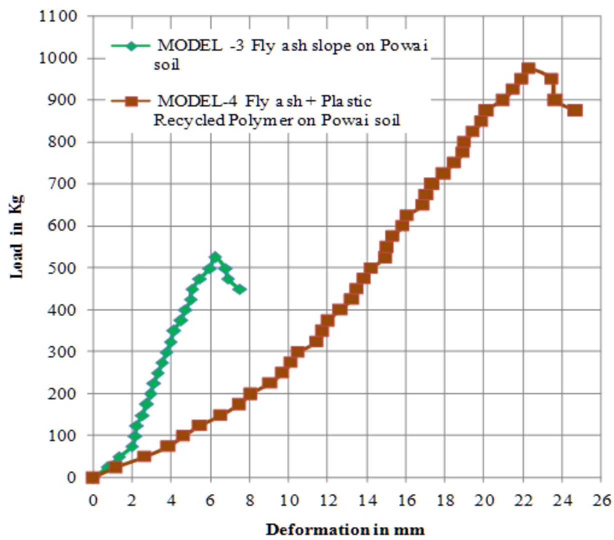


Fig. 7 Load vs Deformation for fly ash under UDL

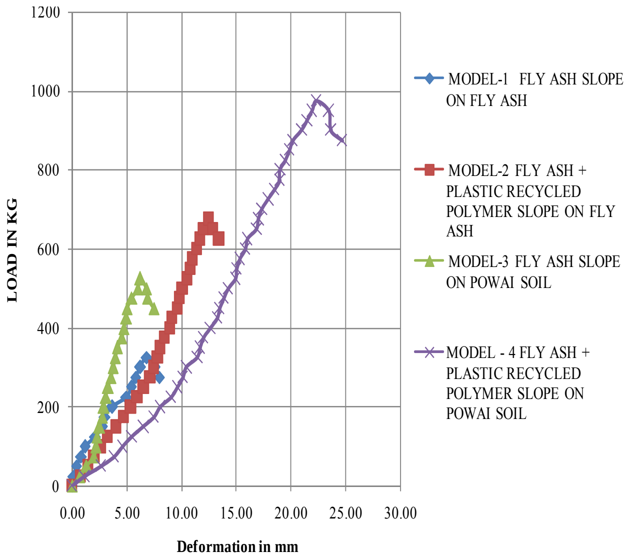


Fig. 8 Load versus Deformation for Fly ash + PRP under UDL

The load and horizontal deformation curve of fly ash slope on rigid foundation for four cases are shown in Fig. 6. The peak values of load at failure and Extreme total deformation are shown in Table II.

V. Finite Element Method for Uniformly Distributed Load- PLAXIS 3D

Model 1: Unreinforced Fly Ash Slope Overlaying Fly Ash Bed

The mesh of fly ash slope before failure and deformed mesh of slope after failure are shown in Figs. 9 and 10 respectively. From Fig. 11, Displacement of fly ash slope is 5.11 mm and from Fig. 12, Factor of safety is 0.9914.

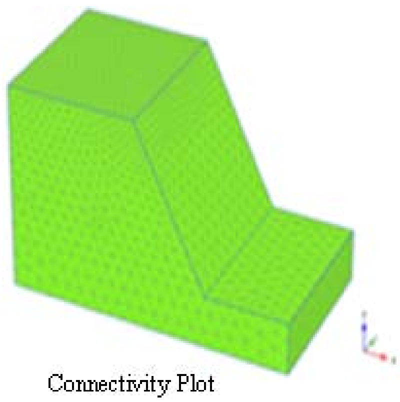


Fig. 9 Fly ash slope mesh before failure (Model -1)

TABLE II
SLOPE MODEL DEFORMATION AND LOAD

Model no.	Loading	Slope material	Foundation soil	Experimental Deformation in mm	Load in Kg
1	UDL	Fly ash	Fly ash	5.2	325
2	UDL	Fly ash + Plastic Recycled polymer	Fly ash	14.95	675
3	UDL	Flyash	PowaiSoil	7.8	525
4	UDL	Flyash + Plastic Recycled polymer	PowaiSoil	19.68	975

Model 2: Fly Ash Slope with Plastic Recycled Polymer Overlaying Fly Ash Bed

The mesh of fly ash slope before failure and deformed mesh of slope after failure are shown in Figs. 13 and 14 respectively. From Fig. 15, Displacement of fly ash slope is 18.24 mm and from Fig. 16, Factor of safety is 1.792.

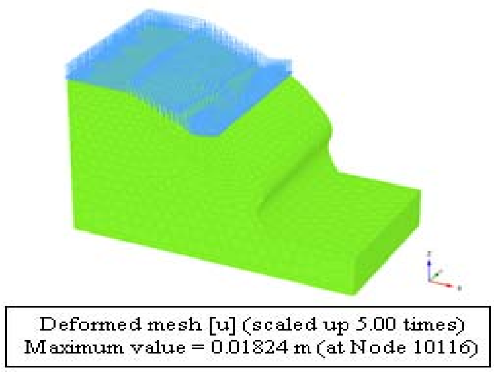


Fig. 10 Fly ash slope mesh after failure (Model -1)

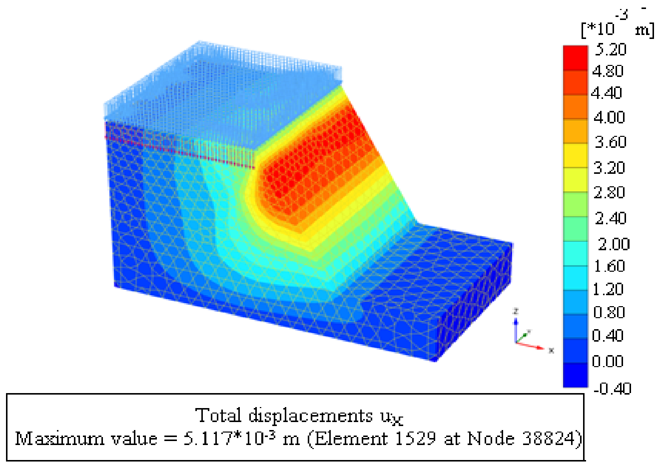


Fig. 11 Displacement of Fly ash slope overlaying fly ash bed (Model-1)

Multipliers				
Prescribed displacements	M_{Disp}	0.000	ΣM_{Disp}	0.000
Load system A	M_{LoadA}	0.000	ΣM_{LoadA}	1.000
Load system B	M_{LoadB}	0.000	ΣM_{LoadB}	1.000
Soil Weight	M_{Weight}	0.000	ΣM_{Weight}	1.000
Acceleration	M_{Accel}	0.000	ΣM_{Accel}	0.000
Strength reduction factor	M_{sf}	0.6334E-3	ΣM_{sf}	0.9914
Time	Increment	0.000	End time	0.000

Fig. 12 Factor of safety fly ash slope overlaying fly ash bed (Model-1)

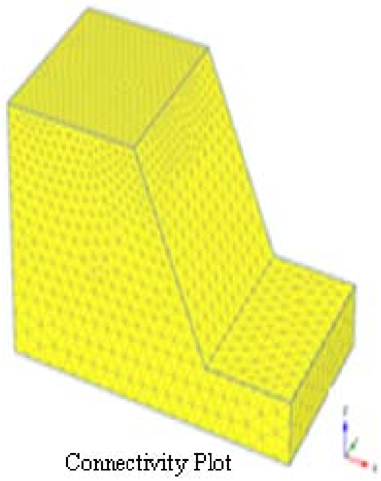


Fig. 13Fly ash + Plastic Recycled Polymer slope overlaying fly ash bed mesh before failure (Model-2)

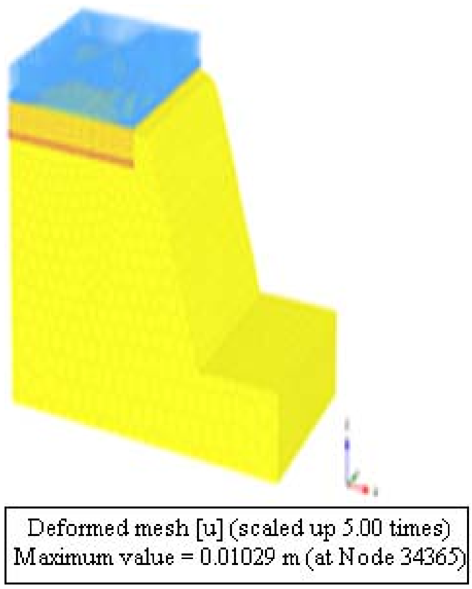


Fig. 14 Fly ash +Plastic Recycled Polymer slope on soft soil mesh after failure (Model 2)

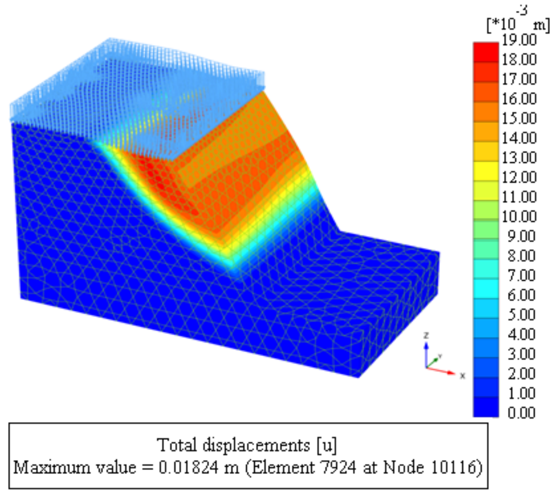


Fig. 15 Displacement of Fly ash +Plastic Recycled Polymer slope on soft soil (Model 2)

Multipliers				
Prescribed displacements	M_{Disp}	0.000	ΣM_{Disp}	0.000
Load system A	M_{LoadA}	0.000	ΣM_{LoadA}	1.000
Load system B	M_{LoadB}	0.000	ΣM_{LoadB}	1.000
Soil Weight	M_{Weight}	0.000	ΣM_{Weight}	1.000
Acceleration	M_{Accel}	0.000	ΣM_{Accel}	0.000
Strength reduction factor	M_{sf}	-0.6219E-3	ΣM_{sf}	1.792
Time	Increment	0.000	End time	0.000

Fig. 16 Factor of safety for Fly ash +Plastic Recycled Polymer slope on soft soil (Model 2)

Model 3: Unreinforced Fly Ash Slope Overlaying Powai Soil

The mesh of fly ash slope before failure and deformed mesh of slope after failure are shown in Figs. 17 and 18 respectively. From Fig. 19, Displacement of fly ash slope is 7.14 and from Fig. 20, Factor of safety is 0.9541.

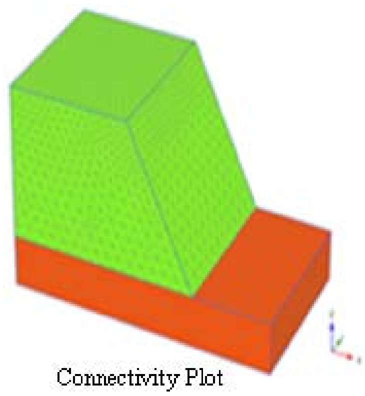


Fig. 17 Fly ash slope overlaying Powai Soil mesh before Failure (Model-3)

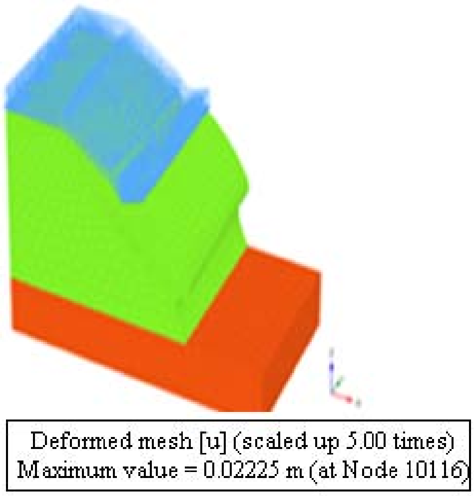


Fig. 18 Fly ash slope overlaying Powai Soil mesh after failure (Model 3)

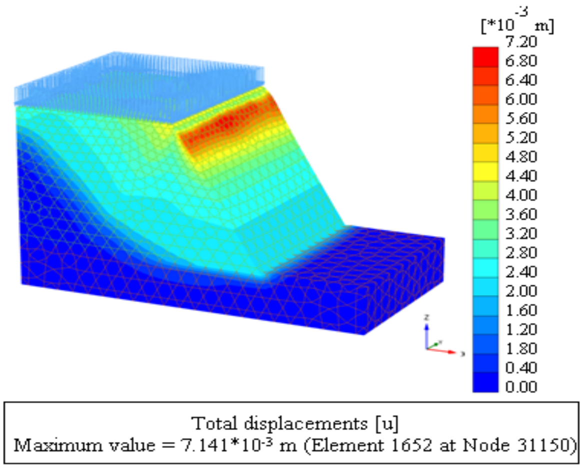


Fig. 19 Displacement of Fly ash slope overlayingPowai Soil (Model 3)

Multipliers				
Prescribed displacements	M_{Disp}	0.000	ΣM_{Disp}	0.000
Load system A	M_{LoadA}	0.000	ΣM_{LoadA}	1.000
Load system B	M_{LoadB}	0.000	ΣM_{LoadB}	1.000
Soil Weight	M_{Weight}	0.000	ΣM_{Weight}	1.000
Acceleration	M_{Accel}	0.000	ΣM_{Accel}	0.000
Strength reduction factor	M_{sf}	1.569E-3	ΣM_{sf}	0.9541
Time	Increment	0.000	End time	0.000

Fig. 20 Factor of safety Fly ash slope on Powai Soil (Model -3)

Model 4: Fly Ash with Plastic Recycled Polymer Slope on PowaiSoil

The mesh of fly ash slope before failure and deformed mesh of slope after failure are shown in Figs.21 and 22 respectively. From Fig. 23, Displacement of fly ash slope is 17.19 mm and from Fig. 24, Factor of safety is 1.525.

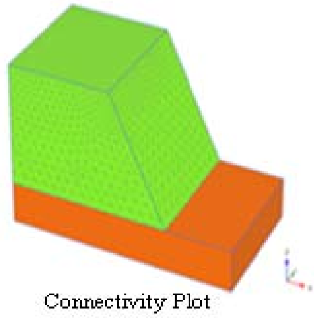


Fig. 21 Fly ash +Plastic Recycled Polymer slope overlaying Powai Soil (Model 4)

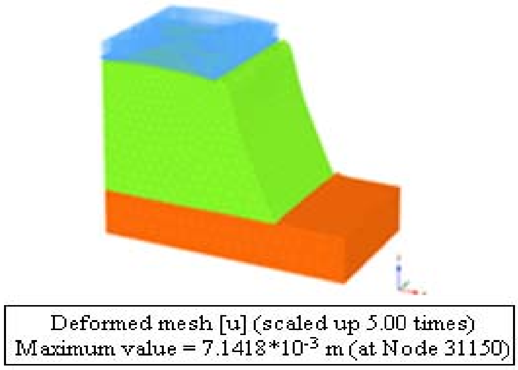


Fig. 22 Fly ash +Plastic Recycled Polymer slope overlaying Powai Soil (Model 4)

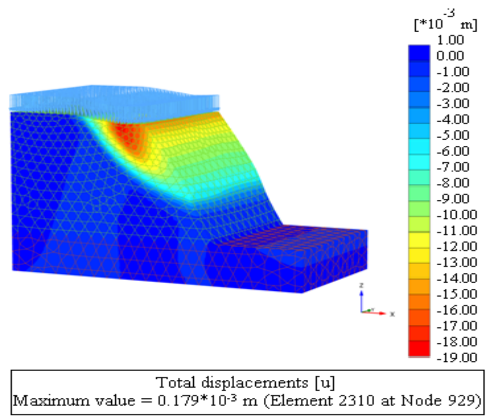


Fig. 23Fly ash +Plastic Recycled Polymer slope overlaying Powai Soil (Model 4)

Multipliers				
Prescribed displacements	M_{Disp}	0.000	ΣM_{Disp}	0.000
Load system A	M_{LoadA}	0.000	ΣM_{LoadA}	1.000
Load system B	M_{LoadB}	0.000	ΣM_{LoadB}	1.000
Soil Weight	M_{Weight}	0.000	ΣM_{Weight}	1.000
Acceleration	M_{Accel}	0.000	ΣM_{Accel}	0.000
Strength reduction factor	M_{sf}	0.7517E-3	ΣM_{sf}	2.525
Time	Increment	0.000	End time	0.000

Fig. 24 Factor of safety for Fly ash +Plastic Recycled Polymer slope overlaying Powai Soil (Model 4)

VI. Result and Discussion

Experimental Investigation:

Load at failure of slope on soft foundation soil: Fly ash and Powai soil foundation.

Several tests are carried out on fly ash slope and fly ash with mixture of Plastic recycled polymer (50%) overlayingfly ash foundation and Powai soil foundation.

TABLE III
Comparison between Experimental and FEM Deformations under Uniformly Distributed Loading

Model no.	Loading	Slope material	Foundation soil	Experimental Deformation in mm	FEM Method Deformation mm
1	UDL	Fly ash	Fly ash	6.20	5.11
2	UDL	Flyash + Plastic Recycled polymer	Fly ash	12.35	18.24
3	UDL	Fly ash	Powai Soil	6.8	7.14
4	UDL	Flyash + Plastic Recycled polymer	Powai Soil	22.30	17.19

It can be observed from Table II that the slope overlaying fly ash foundation gets failed at lower loads as compared to the slope overlayingPowai soil foundation. It is observed that the fly ash with Plastic recycled polymer slope carry more load than that of fly ash slope. This is due to inclusion of plastic recycled polymer in fly ash. For the determination of factor of safety a theoretical method by Bishop's Simplified method was used to find out factor of safety using computer programme; Microsoft Excel.

TABLE IV
Comparison between Experimental and FEM Factor of Safety under Uniformly Distributed Loading

Model no.	Loading	Slope material	Foundation soil	ExperimentalF.O.S	FEM Method F.O.S
1	UDL	Fly ash	Fly ash	0.975	0.991
2	UDL	Flyash + Plastic Recycled polymer	Fly ash	1.937	1.792
3	UDL	Fly ash	Powai Soil	0.64	0.954
4	UDL	Flyash + Plastic Recycled polymer	Powai Soil	2.29	2.525

VII. Finite Element Analysis

The variation of the deformation and factor of safety of the unreinforced fly ash slope and fly ash slope with plastic recycled polymer (50%) overlaying Fly ash bed as well as Powai soil foundation are analyzed using Experimental investigation by Bishop's Simplified method and Plaxis 3D [10].The variation for deformations and factor of safety are shown in Tables III and IV respectively. The variation of Experimental values for factor of safety and deformation of slope are somewhatreasonably lower as compared to Plaxis 3D software results.

VIII. Conclusions

Reinforced slopes are widely used now-a-days because it represents the most economical solution and also provides flexibility. Model test set-up is developed for carrying out tests on unreinforced fly ash slope and fly ash slope with Plastic recycled Polymer 50% overlaying Fly ash bed as well as Powai soil foundation under uniformly distributed loading and strip loading. Properties of fly ash, Powai soil and fly ash inclusion of Plastic Recycled polymer (50%) are found out and eight types of slope are ascertained.

Fly ash is a hazardous waste material and difficult to dump, so it can also be used as a filling material in geotechnical application such as embankments, pavements etc. Plastic Recycled Polymer made up of lower grade recycled Polymer product can be used as a construction material it will lead to clean environment and it does not decompose with time.

- In case of fly ash slope overlaying fly ash bed, the load taken by fly ash slope is 325 kg and as the inclusion of Plastic Recycled Polymer in fly ash the load carrying capacity increases about 675 kg. Similarly, fly ash slope overlaying powai soil as foundation soil then the load carried by fly ash slope is about 525kg and due to inclusion of Plastic recycled polymer in fly ash the load carrying capacity of slope is about975 kg.
- From experimental investigation we conclude that the fly ash slope overlying fly ash bed that is soft foundation soil, the factor of safety for unreinforced fly ash slope is 0.975and with inclusion of Plastic Recycled Polymer in fly ash the factor of safety increases about 1.937. Similarly if fly ash slope is on the powai soil as foundation soil then the factor of safety is 0.64 and due to inclusion of Plastic recycled polymer in fly ash the factor of safety of slope is about 2.290.
- From Finite element method that is PLAXIS 3D software we conclude that the fly ash slope overlying fly ash bed that is on soft foundation soil the factor of safety of fly ash slope is 0.9914 and with the inclusion of Plastic Recycled Polymer in fly ash the factor of safety increases about 1.792. Similarly if fly ash slope is on the powai soil as foundation soil then the factor of safety is about 0.9541 and due to inclusion of Plastic recycled polymer in fly ash the factor of safety of slope is about 2.525.
- Finally, Plastic recycled polymer can be used as a stabilized fly ash slope material to make it steeper and stable. Due to its confinement and inclusion property the slope can take larger loads and produces less deformation.

REFERENCES

[1] S. Edgar, "The use of high tensile polymer grid mattress on the mussel burgh and Portobello Bypass,"*Procee. Engg polymer grid reinforcement in civil engineering*, ICE,London, 1984, pp. 3-5.

[2] N. R. Krishnaswamy, K. Rajagopal, and G. M. Latha, "Model studies on geocell supported embankment constructed over soft clay foundation," *Geotechnical testing journal*, No.23, Vol.1, 2000, pp. 45-54.

[3] S. K. Mhaiskar and J. N. Mandal, "Investigation on soft clay sub grade strengthening using geocells", *Construction and buildingmaterials*, 10(4), 1996, pp. 281-286.

[4] R. K. Rowe and L. J. Mylleville Brian, "The stability of embankment reinforced with steel", *Journal of Canadian geotechnic*, 30, 1993, pp. 768-780.

[5] T. V. Salunkhe and J. N. Mandal, "Behavior of fly ash at different mix ratios with plastic recycled polymers", *International Journal for Research in Applied Science and Engineering Technology (IJRASET*), Vol.2 Issue III, ISSN: 2321-9653, 2014, pp. 190-198.

[6] M. S. Khedkar and J. N. Mandal,"Behavior of cellular reinforced soil wall under uniformly distributed load", *9th International conference ongeosynthetics*, Guaruja, Brazil, 2010, pp.1693 1698.

[7] J. N. Mandal and D. K. Bhardwaj, "Study on polypropylene fibre reinforced fly ash slopes", *12thinternational conference of international association for computer methods and advances in geomechnics*,Goa, India, 3, 2008, pp. 3778-3786.

[8] M. S. Khedkar and J. N. Mandal, "Pullout behaviour of cellular reinforcements", *International Journal of Geotextile and Geomembranes*", 27(4), 2009, pp. 262- 271.

[9] A.W. Bishop, "The Use of the Slip Circle in the Stability Analysis of Slopes", *Geotechnique*, Vol. 5, 1995, pp. 7 - 17.

[10] PLAXIS 3D, Manual, Eds. Brinkgreve, R. B. J., Engine, E. and Swolfs, W. M. with co-operation of D. Waterman, A. Chesaru, P. G. Bonnier and V. Galavi, ISBN-13:978-90-76016-14-6, 2013,Plaxisbv P. O. Box 572, 2600 AN DELFT, Netherland.