CENTRIFUGE MODELLING AND FINITE ELEMENT ANALYSIS OF FIBER REINFORCED FLY ASH SLOPE

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ABSTRACT: Nearly 800 million metric tons of ash is produced each year all over the world. In India presently 97 million metric tons of ash is produced annually by power stations. In view of the large quantities of ash its bulk utilization is essential which is possible only through geotechnical applications such as embankments, backfill material, sub base material and the like.For improving the shear strength of fly ash, fiber reinforcement is mixed with fly ash by weight. Few number of reinforced fly ash slopes have been constructed up to date and are performing well.The deformation behaviour of fly ash slope is studied with and without fiber reinforcement using the Centrifuge modeling technique.A 'REAME' which is a FORTRAN program, stands for Rotational equilibrium analysis of multilayered embankment, coded according to Bishop's simplified method. It uses exhaustive search for the location of critical slip surface and evaluates the corresponding factor of safety (FS). It also evaluates for factor of safety for the given slip surface. A 'REAME' Program has been used, to find out the Factor of Safety slope using the experimental data.The finite element analysis of fly ash slope with and without fiber reinforcement was done using the software 'ANSYS' to find out the deformation of the slope. This analysis which simulates the construction sequence is carried out using non-linear elastic Duncan Chang hyperbolic model.

1 INTRODUCTION

In contrast, randomly distributed discrete fiber-reinforced soil, called "ply-soil", is similar to admixture stabilization in its preparation as shown in figure 1.

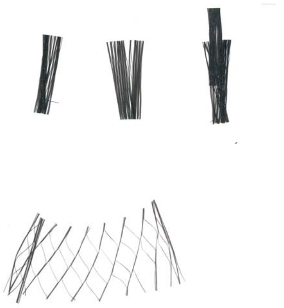

FIGURE 1 POLY PROPYLENE FIBER

The discrete fibers are simply added and mixed randomly distributed fibers in the maintenance of strength isotropy and the absence of potential planes of weakness that can develop parallel to the oriented reinforcement. Fiber-reinforce soil may be used as a soil-improvement technique, with respect to embankment, subgrade / subbase, and other such problems.

Fiber inclusions cause significant modification and improvement in the engineering behavior of soils. A number of research studies on fiber-reinforced soils have recently been carried out by Gray and Lin (1972), Martin and Collins (1989), Sharma and Bolton (1996), Sridharan et al.(1998), Frost and Han (1999), Sivapullaiah and Sridharan (1999), Santoni et al. (2000) and Shenbaga and Vasant (2001). Ranjan et al. (1996) carried out triaxial compression tests on randomly oriented fiber-reinforced soils.

An experimental program was therefore undertaken to investigate the individual and combined effects of randomly oriented fiber inclusions and cement stabilization on the geotechnical characteristics of fly ash-soil mixtures. The fly ash was mixed with the local soils in different proportions and the geotechnical characteristics of the fly ash-soil mixtures were determined. The individual effect of fibers on the geotechnical characteristics was investigated by conducting experiments on fly ash-soil mixtures blended with 1% polyester fibers by weight. Similarly, the individual effect of cement on the strength characteristics was investigated by conducting un-confined compression tests on compacted fly ash-soil specimens prepared with 3% and 6% cement by weight and cured for different periods. The combined effect of fibers and cement on the strength characteristics was investigated by conducting unconfined compression tests on cured fly ash-soil specimens containing 3% cement content and 1% fiber content.

In the present study an effort was made to study the engineering properties of fly ash to investigate its utility as a replacement for earthen material. Centrifuge modeling of unreinforced and reinforced fly ash slope was done with varying water content to study the failure pattern and their behaviour. A non-linear finite element analysis of the reinforced fly ash slope was done using the software ANSYS.

2 EXPERIMENTAL INVESTIGATION

Fly ash samples from the ash disposal pond of Koradi Thermal Power Plant (KTPP) Nagpur, Maharashtra, India were collected for the present study. The geotechnical investigation was carried out on the fly ash sample. The specific gravity of fly ash was found to be 2.19, the grain size distribution showed sand-sized 41%, silt-sized 51% and clay sized 2%, maximum dry density (γ_d) was found to be 1.51 g/cc with a OMC of 20.6%. The angle of internal friction was found to be 31° and the angle of friction of fiber reinforced fly ash at 1% of fiber by weight found to be 47°.

3 CENTRIFUGE MODELLING OF REINFORCED FLY ASH SLOPE

Centrifuge model testing, because of its ability to reproduce the same stress levels in a small-scale model as those present in a full-scale prototype, is a useful tool in the investigation of geotechnical problems. The principle of centrifuge testing is to raise the acceleration of the scaled model in order to obtain prototype stress levels in the model.

Centrifuge modeling is used to investigate the behaviour of unreinforced and reinforced fly ash slope. Centrifuge modeling was done basically to study the performance of the fly ash slope after mixing with fiber reinforcement of 1% by weight. The failure pattern and the deformation behaviour of the reinforced the slope is studied for different moulding water content without and with fiber reinforcement.

3.1 Testing Program and Model Preparation

In the present investigation, it was proposed to study the deformation and stability of fly ash slope without and with fiber reinforcement. The performance of the slopes was studied for different moulding water contents. In order to examine the influence of reinforcement on the stability of fly ash slope, firstly failure behaviour of fly ash slope without reinforcement is evaluated by varying moulding water content For each centrifuge test, the required quantity of fly ash was oven dried for 24 hrs and then cooled in open atmosphere and weighed. The sample was tested for different water contents. The conditioned fly ash sample and water are mixed with hand till a homogeneous mixture is obtained. The mixture is allowed to mature for 48 hours. Proper care is taken to prevent moisture loss. The dimensions of the slope with a model height of 80mm, width of 20mm, length of 100mm(Considering the half of the embankment). In case of reinforced fiber 1% by weight, mixed with fly ash then model was prepared same as in case of unreinforced slope. The inside of the container is coated with silicon grease to minimize frictional effects. The wooden block spacers were placed in such a way that desired geometry of the slope was obtained. After achieving the required height of model wooden block spacer is removed slowly without disturbing the geometry of the slope. A sand paper was used at the bottom to develop roughness between the model and the base of the container.

3.2 Interpretation of Results

The type of failure observed in the fly ash slopes without reinforcement is of catastrophic in nature. After attaining a failure rpm, cracks propagate throughout the width and sudden failure occurs. The failure pattern of unreinforced fly ash slope is shown in figure 2 after the test. The failure rpm for the unreinforced fly ash slope model 602 rpm. It is observed that the consolidation of the fly ash takes place very fast, which is the biggest advantage of fly ash.

On the other hand, it is found that the reinforced fly ash slope is stable and does not give any sudden failure. But, it showed some cracks at a relatively high rpm. The failure rpm (at which the cracks are observed) for reinforced fly ash slope is 620 rpm. . The failure pattern of reinforced fly ash slope is shown in figure 3 after the test. The failure pattern of the unreinforced and reinforced fly ash slope with water content of 25% have been shown in the Figures2 and 3.respectively. The failure of unreinforced slope is catastrophic in nature but the reinforced fly ash wall shows only a very thin cracking and slight lateral deflection of the slope.

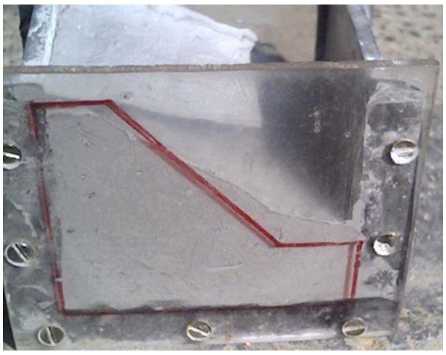

FIGURE 2 DEFORMATION PATTERN OF UNREINFORCED FLY ASH SLPOE AFTER CENTRIFUGE TEST AT WATER CONTENT=25%

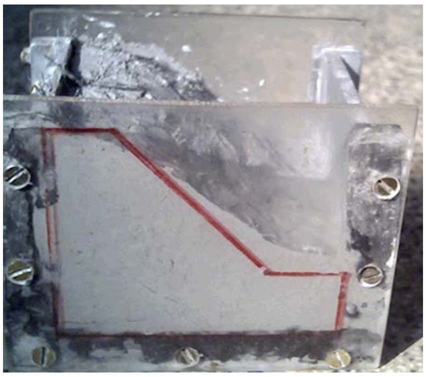

FIGURE 3 DEFORMATION PATTERN OF REINFORCED FIBER FLY ASH SLOPE AFTER CENTRIFUGE TEST AT WATER CONTENT=25%

3.3 Summary of Centrifuge Results

Based on the details obtained from the executed centrifuge test results the following can be summarized:

i) Fly ash slopes without reinforcement are liable to fail and sudden failure of slopes has been noticed.

ii) Unreinforced fly ash slope shows a sharp decrease in the strength for water content on higher side of optimum moisture content.

iii) The consolidation in fly ash is quick. It takes sometime to mature when mixed with water but its consolidation is fast. Proper drainage should be provided to drain the water.

iv) Reinforced fly ash slope shows little cracking and small deflection of panel slope, even at very high rpm.

4 FACTOR OF SAFETY

Factor of safety of reinforced and unreinforced fly ash slope was found by using a program called REAME, which is based on the Bishop's slip circle method of slope stability. In case of unreinforced slope the Factor of safety is 0.65, and fiber reinforced case 1.20, and the slip surface for a given Minimum Factor of Safely for unreinforced and reinforced slopes has shown in figures 4 and 5 respectively. The soil parameters are given in Table 1.

Table 1 Properties of soil

Property	Unreinforced Fly Ash	Reinforced Fly Ash
Cohesion(c) (KN/m^2)	0	O
Angle of Internal Friction(φ)	31^o	47^o
Unit Weight (γ) (KN/m^3)	15.1	15.1
Poisson Ratio	0.4	0.4

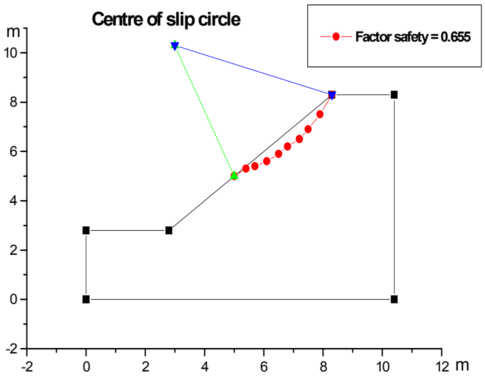

FIGURE 4 SLIP SURFACE OF UNREINFORCED FLY ASH SLOPE

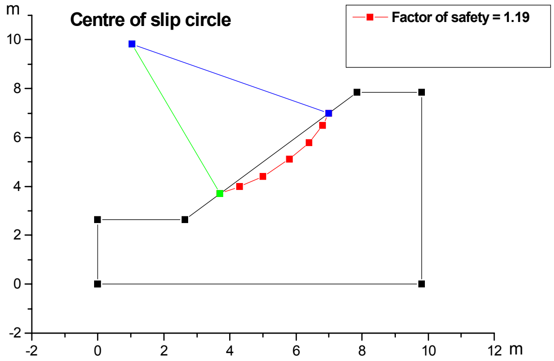

FIGURE 5 SLIP SURFACE OF FIBER REINFORCED FLY ASH SLOPE

5 FINITE ELEMENT ANALYSIS OF REINFORCED FLY ASH SLOPES

A non-linear finite element method of analysis is used for the analysis and study of fiber reinforced fly ash slopes which were found to be satisfactorily stable after the centrifuge tests. The problem is considered as plane strain problem. The finite element analysis work reported in this paper was performed using finite element software ANSYS. The finite element mesh used for the numerical simulation of reinforced and unreinforced fly ash slopes is as shown in the figure.6.

Eight noded quadrilateral element (PLANE82) deforming in plane strain is used for descretizing the fly ash medium. It is considered as a non-linear elastic material. The Duncan Chang hyperbolic model is used to model the non-linear behaviour of the fly ash . The stress strain behaviour of any type of soil depends on the number of different factors such as density, water content, structure , drainage conditions, strain conditions (i.e. plane strain, triaxial), duration of loading , stress history, confining pressure and shear stress. The expression for the Initial modulus value for any stress condition is expressed as

$$\mathrm{E}_i = \mathrm{KP}_a\left(\frac{\sigma_3}{\mathrm{P}_a}\right)^n$$

Drained triaxial tests were carried out on the fly ash sample for estimation of hyperbolic soil parameters in the current FEM simulation of unreinforced and fiber reinforced fly ash slopes. They are tabulated as shown inTable2.

Table 2 Properties of fly ash

Property	Fly ash	Fiber reinforced fly ash
Dimensionless modulus number	200	158
Exponent (n)	0.59	0.41
Cohesion (c) kN/m^2	0	0
Angle of internal friction (φ)	31^o	47^0
Unit Weight (γ) (KN/m^3)	15.1	15.1
Poisson's ratio (η)	0.4	0.4

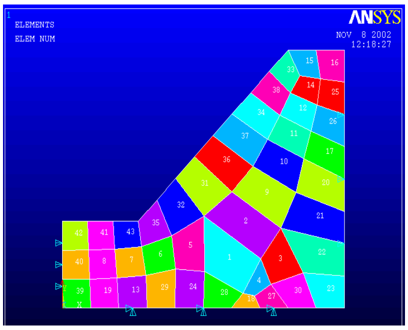

FIGURE 6 UNREINFORCED AND REINFORCED FLY ASH SLOPE MESH

6 FINITE ELEMENT ANALYSIS RESULTS

From ANSYS, the Vector plot for unreinforced and fiber reinforced fly ash slope are shown in figures 7 and 8 respectively. Deformed and undeformed shapes of unreinforced and reinforced fly ash slope are shown in figures 9 and 10 respectively.

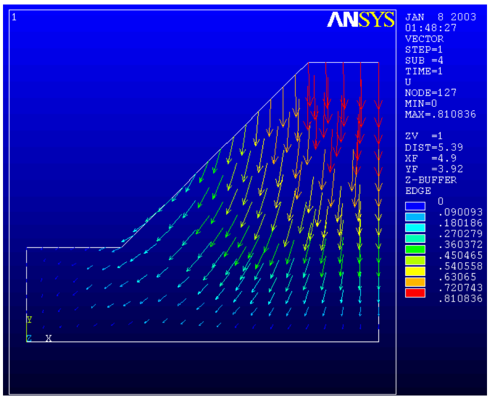

FIGURE 7 VECTOR PLOT FOR UNREINFORCED FLY ASH SLOPE

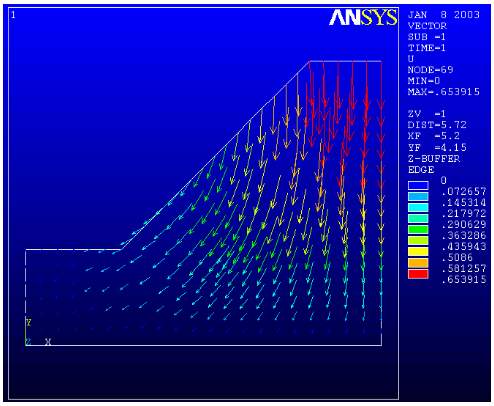

FIGURE 8 VECTOR PLOT FOR FIBER REINFORCED FLY ASH SLOPE

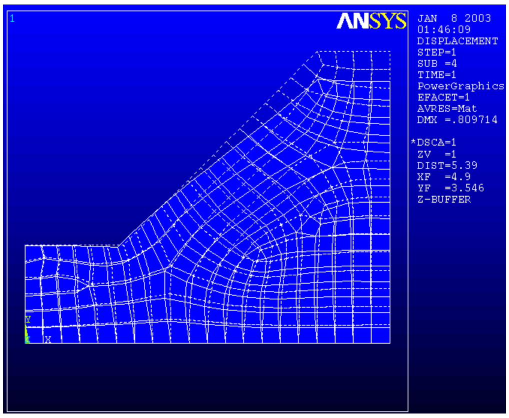

FIGURE 9 DEFORMED AND UNDEFORMED SHAPE OF UNREINFORCED FLY ASH SLOPE (….UNDEFORMED, ____ DEFORMED)

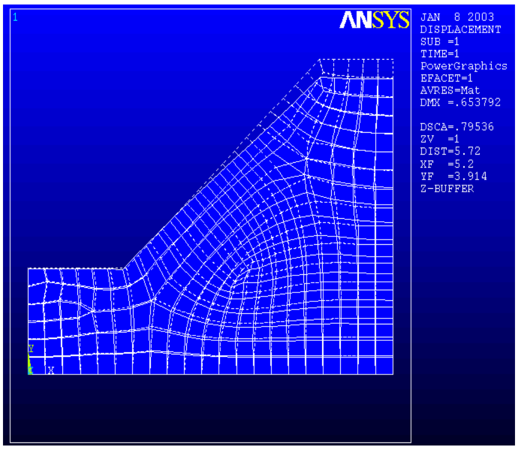

FIGURE 10 DEFORMED AND UNDEFORMED SHAPE OF FIBER REINFORCED FLY ASH SLOPE (….UNDEFORMED, ____ DEFORMED)

7 CONCLUSION

It has been observed that fly ash slopes without reinforcement failed in the centrifuge test at low rpm. This indicates that they are liable to fail and sudden failure of slope has been observed during the test.. The reinforced fly ash slopes performed satisfactorily even at very high rpm . Hence, it can be inferred that the reinforced fly ash slopes does not fail suddenly and their strength is much higher than that of the unreinfirced slopes.From Bishop's method it has been observed that, the Factor of safety of a fiber reinforced slope increased as compared to the unreinforced slope. From ANSYS, in unreinforced slope more displacement has been observed with respect to the fiber reinforced fly ash slopes and also from centrifuge experiments, in unreinforced slopes more settlement has been observed. The vector pattern from the ANSYS represents the nature of probable failure surface.

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