International Journal of Engineering Inventions
ISSN: 2278-7461, www.ijeijournal.com
Volume 1, Issue 1(August 2012) PP: 16-23

Application of Geo-Grid Reinforcement Techniques for Improving Waste Dump Stability in Surface Coal Mines: Numerical Modeling and Physical Modeling

I L Muthreja[1], Dr R R Yerpude[2], Dr J L Jethwa[3]
[1,2]Associate Professor in Mining Engineering, Visvesvaraya National Institute of Technology, Nagpur, India
[3]Former Director-level Scientist, and Scientist-in-charge, Central Mining Research Institute, Nagpur Regional Centre, presently a Tunneling Consultant

***Abstract*—The increase demand of coal production in India can only be achieved through the mechanised surface method of mining. Reserves from shallow depths are depleting and surface coal mining has to go deeper and deeper day by day. This will result in increase in the volume of waste rock and dumping area. The problem of land acquisition along with stringent environmental law will compel the coal companies to have waste dumps of more height. Higher waste dumps can only be planned and constructed by using earth reinforcement techniques using geogrids. As geogrids have not been used in waste dumps of Indian coal mines, numerical models and physical models are developed to study the role of geogrids in waste dump stability. This paper discusses the comparison of dump stability analysis results of numerical modeling and results of physical modeling.**

***Keywords*—Factor of safety, Geogrids, Waste dumps**

I. INTRODUCTION

Coal is the major source of energy in India and, at the moment, more than 55% of principal energy consumption is being met by this natural resource. Proven geological reserve of coal in the country makes it the most potential source to sustain the growing demand of energy due to economical development of the country. Even after advent of the nuclear energy, the dominance of coal is likely to continue due to different techno-economical and safety reasons. This tremendous increase in the coal production can only be achieved through the mechanised surface mining with increase waste rock handling. Reserves from shallow depths are depleting fast and surface coal mining has gone deeper in coming days. This will result in increase in the volume of waste rock which will need more dumping area. The problem of land acquisition along with stringent environmental law, the coal companies are bound to have higher dump yards.

The waste dump management is a very complex issue which depends on numerous factors. Some factors are within the control of the planners and mine operators but certain factors are not. Land constraints as well as increase in stripping ratio will force the planners and operators to go for increasing dump heights of the existing dumps. Thus, it is a future essential necessity to have large waste dumps with steeper slopes in opencast coal mines for ecological and economic reasons. But larger heights dumps with steeper slopes are associated with increased instability aspects, necessarily require better waste dump stability management.

Steepened slopes with higher dumps have become increasingly advantageous due to better land usage and lower site development costs. The proven concept of tensile reinforcement allows construction of dumps with improved stability, than are possible with the present practice with poor dump stability. Dumps reinforced with geo-synthetics/geo-grids can reduce land requirement substantially, provide a natural appearance, and improve dump stability and safety.

The application of geogrids has been modeled numerically using FLACSLOPE software developed by M/s ITASCA, USA. To compare these results, physical modeling has been done in the laboratory and experiments were performed.

II. GEOGRIDS

For millennia, civilizations have sought effective methods to construct stable soil retaining structures. The technique of reinforced soil is not a new concept. In a modern context, reinforced soil has become a viable and cost-effective technique only over the last 30 years. This was brought about by the development of geogrid reinforcements engineered from strong and durable polymers. These geogrid reinforcements enable substantial tensile loads to be supported at defined deformations over extended design lives.

Reinforced soil is the technique where tensile elements are placed in the soil to improve stability and control deformation. To be effective, the reinforcements must intersect potential failure surfaces in the soil mass. The fig.1 illustrates the principle of geogrids application. Strains in the soil mass generate strains in the reinforcements, which in turn, generate tensile loads in the reinforcements. These tensile loads act to restrict soil movements and thus impart additional shear strength. This results in the composite soil/reinforcement system having significantly greater shear strength than the soil mass alone.

Reinforced soil using geogrids is a very effective technique. The major benefits of reinforced soil are:

- The inclusion of geogrid in soil improves the shear resistance of the soil thereby improving its structural capability.
- Land acquisition can be kept to a minimum because reinforced structures can be made steeper and higher than would otherwise be possible.

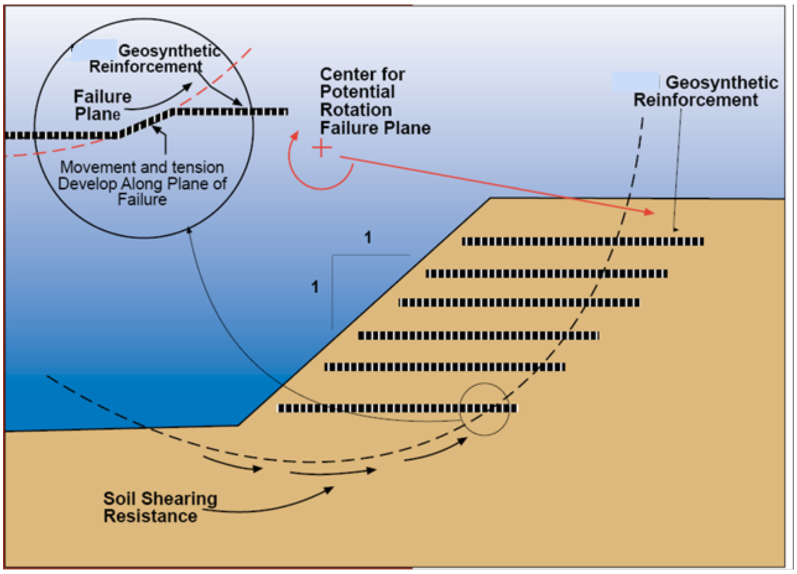

Fig 1- Geogrid reinforcement of slope

Geogrid reinforcements are manufactured from highly durable polymers that can maintain strength, stiffness, and soil interaction over extended design lives. Typical design lives may range from 1 to 2 years for a temporary reinforced soil structure, to 120+ years for a permanent reinforced soil structure. Fig-2 shows a typical geogrids

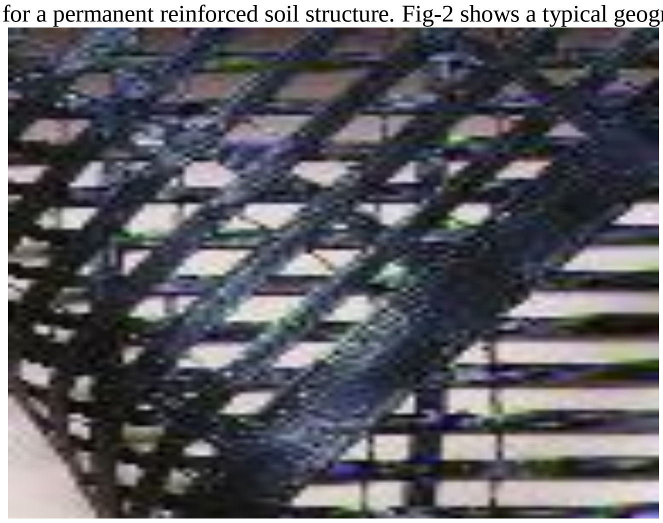

Fig.2. A typical geogrid

The use of geogrids has not been applied in the Indian coal mining industry as yet. Coal mine waste dumps consist of loose broken rock material mainly consisting of sandstone, shale, and soil. The behavior of this material is similar to soil as discussed above. The use of geosynthetics/geogrids will definitely help in improving the stability of waste dumps.

III. WASTE DUMP STABILITY ANALYSIS USING NUMERICAL MODEL:

Representative samples from existing waste dumps in coal mines were collected and tested for determination of material characteristics. The results are shown in Table-1

Table 1: Waste dump and floor material characteristics

Sample	Density, kN/m^3	Cohesion, kN/m^2	Friction Angle, Degree
Dump (Broken Overburden Material)	20.02	24.0	27.5

Floor soil (Black Cotton Soil)	20.96	39.0	20.9

For modeling, above characteristics of the material from a surface coal mine have been used
The following properties of geogrids were used for numerical modeling:
Bond Cohesion= 1000 N/m
Bond Friction angle= 10^0
Thickness = 5 mm
FLAC SLOPE numerical modeling software is used for stability analysis of waste dump. The analysis was performed by introducing Geogrids in the waste dump in the following way:

a. Basic Waste dump, without any geogrid
b. One layer of geogrid at a height of 25% of total dump height
c. One layer of geogrid at a height of 50% of the total dump height
d. Two layers of geogrid, one at a height of 25% and other at 50% of the total height of dump

The following figures (1-4) show the results of modeling and the stress contours:

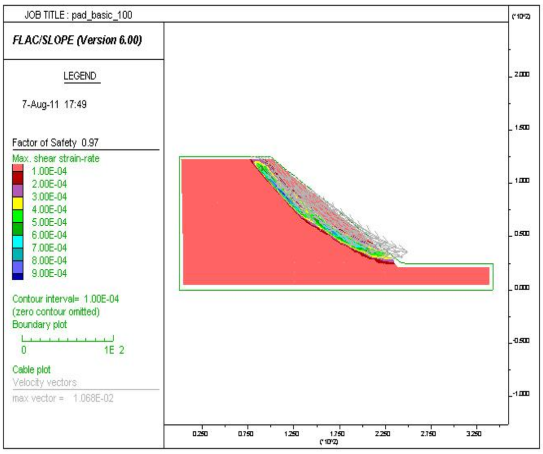

Fig.1 Basic waste dump model without any geogrid

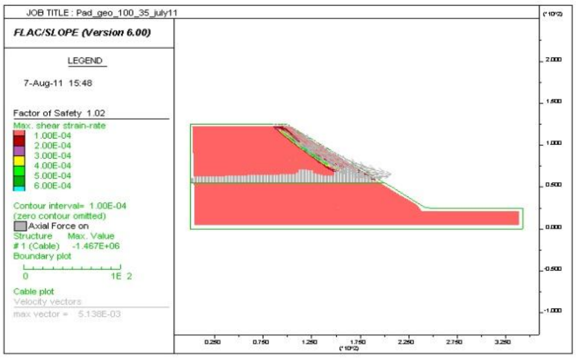

Fig.2 Waste dump model with one layer of geogrid at 25% of dump height

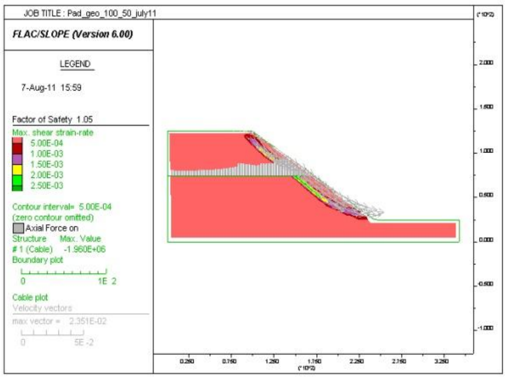

Fig.3 Waste dump model with one layer of geogrid at 50% of dump height

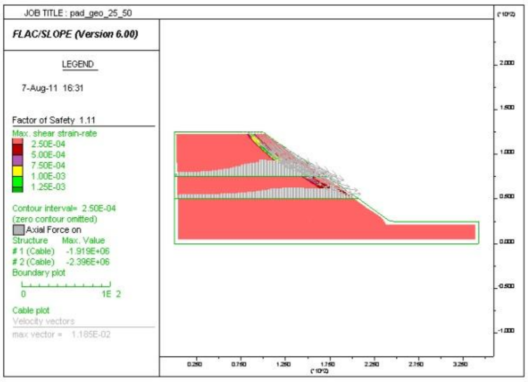

Fig.4 Waste dump model with two layer of geogrid one at 25% and other at 50% of dump height

The Numerical Modeling results give factor of safety of waste dump in each case.
The table-2 shows the factor of safety as determined by Numerical Modeling for different conditions.

Table2- Waste dump stability analysis using FLACSLOPE Numerical Modeling Software

Sr. No	Case	Factor of Safety by Numerical Modeling
1	Simple	0.97
2	Geogrid_25 %	1.02
3	Geogrid_50 %	1.05
4	Geogrid_25_50 %	1.11

The above results indicate increase in factor of safety with application of Geogrids in various combinations.

IV. WASTE DUMP PHYSICAL MODELING:

The geogrids have not been used in coal industry in India; hence validation of the numerical modeling results with field study is not possible. Considering this constraint, physical model was prepared and experiments were performed on the physical model to compare the results from numerical modeling qualitatively.

A model of acrylic sheets having a dimension 300 mm X 300 mm X 450 mm was prepared on a tilting platform. Road metal dust was used for constructing the dump and the failure was induced by increasing the slope of base, the tilting platform. The plastic net resembling geogrids was used for the experiment. The model details are shown in figure 5.

Following Procedure has been adopted for conducting experiments with physical model:

1. Same material has been used for all cases
2. Same dump configuration has been used for all cases
3. Dumps are stable under normal level floor conditions

4. The failure is induced by increasing the dip angle of the floor gradually

The hypothesis used for the experimentation is that the modeled dump, which fails at higher slope of base platform, will have higher stability under normal level base platform conditions.

The following experiments of monitoring failure, having same conditions as that of Numerical Modeling, were performed:

a. Base model without use of geogrid
b. One layer of geogrid at the height of 25% of total dump height
c. One layer of geogrid at the height of 50% of total height
d. Two layers of geogrid, one at a height of 25% and other at 50% of the total height of dump

The figures 5-13 show the experiments performed as above

Fig.5 Basic Model without any geogrid

Fig.6 Basic Model without any geogrid another view

Fig.7 Basic Model without any geogrid at failure

Fig.8 model with one layer of geogrid at 25% of dump height

Fig.9model with one layer of geogrid at 25% of dump height another view

Fig.10 Physical model with one layer of geogrid at 50% of dump height

Fig.11 Physical model with one layer of geogrid at 50% of dump height, another view

Fig.12 Physical model with two layers of geogrid one at 25% and another at 50% of dump height

Fig.13 Physical model with two layers of geogrid one at 25% and another at 50% of dump height, at failure

The results of physical model are shown in the table-3

Table-2: Results of Physical Modeling

Sr. No	Case	Dip Angle of the Floor at failure, Deg
1	Basic model	12.33
2	Geogrid_25	17.50
3	Geogrid_50	20.00
4	Geogrid_25_50	22.00

The results of Numerical Modeling (Table-1) and Physical modeling (Table-2) show similar trend. This validates the results of Numerical Model. Hence other parametric studies can now be performed using Numerical Modeling. This experimentation will open the applicability of geogrids in coal mining industry for improving the stability of waste dumps, thereby planning higher dumps to save on dumping land required.

V. CONCLUSIONS

This study is an attempt to introduce geogrids in improving stability of coal mine waste dumps. The results from Numerical and Physical Modeling show similar trend in respect of stability of waste dumps. This proves the application of geogrids in improving the stability of coal mine waste dumps. Thus by using geogrids, higher dumps, accommodating large overburden, can be designed. The coal mining industry will certainly be relieved from the problem of land acquisition, which is becoming difficult day by day in India and at the same time ensuring the stability of waste dumps.

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