Slope Stability of Opencast Coal Mine Dump — A Case Study

S. K. Chaulya*

One of the problems associated with open pit mining is the disposal of a large volume of overburden waste material or spoil, that ranges through silts and clays to large size boulders. Miller et al (1979), classified spoil materials into three groups viz., predominantly soil spoil, mixed soil and rock spoil, and predominantly rock spoil. The storage of waste material from mining operations should be performed keeping in view the danger to men and properties posed by the failure of dump slopes. The parameters of resource recovery, mining cost, safety and environment are influenced by the instability of waste dumps. Increasing emphasis on openpit mining has aggravated the problems.

Spoil of the mine dump consists of a combination of coarse and fine material. The stability of a particular opencast mine dump exhibiting shallow circular failure surfaces is analysed by the Sarna limit equilibrium method. Stability analyses based upon equilibrium methods are considered to be applicable for the soft and loose materials involved. An approach is given to stabilize the slopes.

LIMIT EQUILIBRIUM METHOD

The limit equilibrium method of slope stability analysis has been widely used for designing slopes in spoil or loose and weathered rocks. It has been found to be satisfactory and sufficiently simple to be employed for practical problems. There are at present several methods of stability analysis which apply the equilibrium principle. Most of these methods utilize the technique of slices and the available strength is computed on the basis of Mohr-Coulomb's failure criterion (Sarma, 1979). The methods mainly differ in the shape of the assumed slip surfaces and in the handling of indeterminacy of the problem. A free body diagram of soil mass, bounded by the top surface is analyzed using statistical equations. Strength parameters and pore pressure distributions are assigned to the cross-section, based on laboratory testing.

Two important aspects of stability analysis by the equilibrium method are the determination of the factor of safety (FOS) and locating the critical slip surface:

(a) The factor of safety is commonly defined as the ratio of available shear strength of the soil to the shear resistance required to maintain equilibrium. The factor of safety is given by:

\[
FOS = \frac{\text{Shear strength available to resist sliding}}{\text{Shear stress mobilized along failure surface}}
\]

In the context of the limit equilibrium method, the factor of safety is defined as that factor by which the shear strength parameters must be reduced in order to bring the potential failure mass into a state of limiting equilibrium. When the material has both cohesion (c) and angle of internal friction (\(\phi\)), it is usual to apply the same factor to both, and \(\tan \phi\): Denoting the reduced parameters by an apostrophe, and the factor by \(k\):

\[
c' = c/k
\]

\[
\tan \phi' = \tan \phi / k
\]

Then, \(k = FOS\), when \(c'\) and \(\phi'\) are associated with incipient failure.

Generally spoil dumps are designed with a factor of safety of 1.1 to 1.15 and present only a minor risk of failure (Miller et al, 1979; D’Andrea et al, 1982; Khandelwal & Mozumdar, 1987 b; Melnikov & Chesnokov, 1969). Spoil dumps engineered for a factor of safety less than 1.1 are subject to greater risks even with accurate data, owing to anomalous conditions such as the heights of spoil material or underlays which are likely to occur throughout the dump (Khandelwal & Mozumdar, 1987; Yudhbir & Basudhar, 1989;

*Scientist, Central Mining Research Institute, Bawana Road, Dhanbad - 826 001 (INDIA)
Coates, 1972). Table 1 illustrates the minimum factor of safety recommended for the design of waste dumps.

(b) The critical failure surface is the slip surface which has the lowest factor of safety. Since all other slip surfaces result in higher factors of safety, any method of analysis that does not determine the critical slip surface will result in unsafe situations. The Fellenius method can be used for the determination of the critical failure surface (Funnie, 1987; Nguyen, 1965).

**SARMA LIMIT EQUILIBRIUM METHOD**

Sarma (1979) limit equilibrium method analysis is a general method to determine the stability of slopes of a variety of shapes. Slopes with complex profiles with circular, non-circular, or planar sliding surfaces or any combination of these, and active-passive wedge failures can be analysed utilizing this method. The analysis allows different shear strengths to be specified for the side and base of each slice. External forces can be included for each slice, and submergence of any part of the slope is automatically incorporated into the analysis.

A closed form solution is used to calculate the critical horizontal acceleration \( K_h \) required to induce a state of limiting equilibrium in the sliding mass. The static factor of safety (FOS) is determined by reducing the shear strength values \( \tan \phi \) and \( c \) to \( \tan \phi_{FOS} \) and \( c_{FOS} \) until the critical acceleration \( K_h \) is reduced to zero.

In order to assess whether the analysis is acceptable, a check is carried out to determine whether all the effective

<table>
<thead>
<tr>
<th>STABILITY CONDITION</th>
<th>Suggested Minimum Design Values for factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CASE A</td>
</tr>
</tbody>
</table>

**STABILITY OF DUMP SURFACE:**
- Short Term (During construction) 1.0 1.0
- Long Term (reclamation - abandonment) 1.2 1.1

**OVERALL STABILITY (DEEP SEATED STABILITY):**
- Short Term (Static) 1.3 - 1.5 1.1 - 1.3
- Long Term (Static) 1.5 1.3
- Pseudo-Static (earthquake) 1.1 - 1.3 1.0

**CASE A:**
- Low level of confidence in critical analysis parameters,
- Possibly unconservative interpretation of conditions, assumptions,
- Severe consequences of failure,
- Simplified stability analysis method (Charts, simplified method of slices),
- Stability analysis method poorly simulates physical conditions,
- Poor understanding of potential failure mechanism(s).

**CASE B:**
- High level of confidence in critical analysis parameters,
- Conservative interpretation of conditions, assumption,
- Minimal consequences of failure,
- Rigorous stability analysis method,
- Stability analysis method simulates physical conditions well,
- High level of confidence in critical failure mechanism(s).
normal stresses acting across the base and side of each slice are positive.

DETERMINATION OF INDEX AND SHEAR STRENGTH PROPERTIES OF THE WASTE MATERIAL

Two waste dumps of an opencast coal mine have been chosen for estimation of slope stability, samples have been collected from waste dumps and laboratory analysis for the spoil material carried out, (Singh & Punmia, 1970; Taylor, 1962; Jumkis, 1965; Afanasjev, 1976; Lambe, 1977; Desa, 1986; Hribar et al, 1986; Punmia, 1987). Final results of the laboratory test are given in Table 2.

| Table 2 |
| Summary of the Laboratory Test Results |
| Sl. No. | Parameter | Value |
| 1. | Water content | 5.5% |
| 2. | Specific gravity (G.) | 1.864 |
| 3. | Void ratio (e) | 0.757 |
| 4. | Porosity (n) | 43.1% |
| 5. | Degree of saturation (s) | 18.63% |
| 6. | Unit weight (γ) | 14.32 KN/m³ |
| 7. | Sieve analysis | Gravel = 11% |
| | | Sand = 89% |
| 8. | Direct shear test | c = 6.1 kPa |
| | | e = 31° |
| 9. | Triaxial test | c = 5.4 kPa |
| | | e = 30° |

ESTIMATION OF SLOPE STABILITY OF THE MINE DUMPS

Fig. 1 shows the layout of overburden dump of an opencast coal mine with reduced levels and ground contours at 5 m intervals. Stability analysis has been carried out for five places on the two dumps (marked as A, B, C, D and E on the plan).

The following assumptions are made to derive the stability of dump slopes:

- The soil is assumed to be in a state of plastic equilibrium.
- The soil is considered to be homogeneous in directions normal to the cross-section.
- The factor of safety is the same value along all segments of the potential failure surface.
- The shear strength of the material is characterized by a cohesion c and a friction angle ø which are related by the equation:
  \[ \sigma = c + \phi \tan \phi \]
- Failure is assumed to occur on a circular failure surface which passes through the toe of the slope.
- Shear strength parameters (c, ø) are determined in the laboratory with great certainty.
- There are no external forces acting on the dump.
- The ground water table lies much below the foundation surface and the soil mass is free draining in nature. Thus, water and pore pressures in the dump are negligible, except in the rainy season (Robertson, 1986).
- The base is assumed to be competent, and will not fail.

The stability analysis has been carried out by the Sama limiting equilibrium method and a summary of the stability analysis is given in Table 3. It has been seen that the dump site A and B are at the limit of stability and failure can occur.

| Table 3 |
| Summary of the Stability Analysis |
| Sl. No. | Dump Site | Height (m) | Slope Angle (deg) | FOC |
| 1. | A | 63.6 | 37.50 | 1.07 |
| 2. | B | 63.9 | 36.00 | 1.03 |
| 3. | C | 68.6 | 30.15 | 1.45 |
| 4. | D | 48.8 | 34.88 | 1.37 |
| 5. | E | 66.5 | 31.15 | 1.44 |

CONCLUSIONS AND RECOMMENDATIONS

The original geometry of the dumps has been shown to be potentially unstable. In the rainy season, failures occur as the unit density of the spoil material increases as voids are filled with water and increase in pore pressure. In addition, the shear strength of the dump decreases sufficiently to pose a serious threat to life, property and access to the pit. Extensive changes in the geometry of the dumps and other preventive measures are, therefore, required to improve stability.

The following actions may be taken to stabilize the dumps:

1. Gebions may be used for the construction of retaining structures. They are rectangular cages made of hexagonal steel wire mesh laced together and filled with stones.
2. Wire netting along the slopes with reinforcement by long bolts/pegs.
3. Construction of a retaining wall at the toe of the dump.
4. Compaction of spoil at the toe of the dump.
Fig. 1: Plan of overburden dumps of an opencast coal mine with R.L. and ground contours
5. Benching of the dump slope. A bench can be constructed near the crest of the dump and excavated material can be spread over the top of the dump (Brawner, 1970; Chaulya & Singh, 1992; Smith et al., 1978).


Repair work should be scheduled to increase stability progressively. Careful planning is necessary to ensure that adverse secondary effects do not arise from the changes made in the site by repair work. Several factors should be considered in planning for dump stabilization measures:

1. Continual clean-up operations in the toe area, though necessary for maintaining access to the pit, have a destabilizing influence.

2. The potential erosion which may occur if a stable weathered surface is disturbed.

3. The exposure of weak zones which adversely affect dump stability.

4. The possibility of earth moving operations temporarily reducing the stability of any area of the dump. An incorrect sequence of earth moving operations could lead to instability.

5. The long-term effectiveness of the proposed work.

ACKNOWLEDGEMENT

The author would like to express his gratitude to Prof. J. G. Singh, Head, Department of Mining Engineering, Banaras Hindu University (B. H. U.), under whose guidance these studies were considered. He would also like to thank Dr. C. Ghosh, Lecturer, Deptt. of Civil Engg., B. H. U., for his help and support in this work.

REFERENCES


LAMBE, W. T. (1977) : Soil testing for engineers, Wiley Eastern Ltd., New Delhi, India.


YUDHIVIR and BASUDHAR, P. K. (1989) : Mechanics of spoidump instability & relevant geotechnical design aspect, Third National Seminar on Surface Mines, Dhanbad, pp. 5.5.1-5.5.9.

MINETECH

S & T SPECIAL

Organizations engaged in various S & T projects are welcome to contribute technical papers to be included in our forthcoming special issue.

Papers dealing with ongoing or completed Coal S & T projects may be sent (conforming to the format followed by MINETECH) to the Chief General Manager (MT, S&T and ME), CMPDI Ltd., Gondwana Place, Kanke Road, Ranchi so as to reach him before the 31st January, 1996.

NEW RATES OF HONORARIUM

The honorarium payable to the authors etc. contributing to MINETECH has been revised. The new rates are as follows :

1. Writing in English — Rs. 90/- for 1000 words
2. Writing in Hindi — Rs. 150/- for 1000 words
3. Vetting — Rs. 15/- for 1000 words
4. Proof Reading — Rs. 10/- for 1000 words