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Slope Stability of Opencast Coal Mine Dump — A Case Study

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बृहद स्तर पर अधिभार निष्कासन एवं सीमित क्षेत्र में अधिक आयतन के भंडारण की आवश्यकता ने अपशिष्ट ढेर के स्थायित्व को महत्वपूर्ण बनाया है ढेर की विफलता की समस्याओं ने चानक मार्ग एवं घाटियों में अवरोध के स्थानीय एव अस्थायी प्रभाव डाले हैं।

इस आलेख का उद्देश्य खुली खान के अधिभार ढेर की ढाल के स्थायित्व का आकलन करना है। सूचक गुणों एव अपरूपण सामर्थ्य प्राचलों के आकलन के लिये अधिभार ढेर का मृदा परीक्षण किया गया है। अधिभार पदार्थ के प्रयोगशाला परीक्षण आँकड़ों का प्रयोग करते हुए विभिन्न अपशिष्ट ढेर के ढाल स्थायित्व का अध्ययन किया गया है।

ढेर के स्थायित्व के आकलन के लिये सरमा सीमा सन्तुलन विधि (1979) का किया गया है। यह पाया गया है कि ढेर मूल ज्यामिति में अस्थिर होता है तथा ढेर के ढाल की विफलता को रोकने के लिये विभिन्न स्थायित्व तकनीकों का प्रयोग आवश्यक होता है।

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 opencast 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 Sarma 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 equilibirum 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 priniciple. 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 analysed 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 :

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

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 equilibirum. When the material has both cohesion (c) and angle of internal friction (ϕ), it is usual to apply the same factor to c 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 ϕ' 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 & Chesnokove, 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 (Khendelwal & Mozumdar, 1987; Yudhbir & Basudhar, 1989;

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Coates, 1972). Table 1 illustreates 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 Fellenious method can be used for the determination of the critical failure surface (Punmia, 1987; Nguyen, 1985).

SARMA LIMIT EQUILIBRIUM METHOD

Sarma (1979) limit equilibirum 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 planer 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_c) 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 ø and c to tan ø/FOS and c/FOS until the critical acceleration K_c 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 1

Suggested FOS for Different Conditions

(After British Columbia Mine Waste Rock Pile Research Committee, 1991)

STABILITY CONDITION	Suggested Minimum Design Values for factor of Safety	
	CASE A	CASE B
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; Tayor, 1962; Jumkis, 1965; Afanasyev, 1976; Lambe, 1977; Desai, 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

1.	Water content			5.5%
2.	Specific gravity (G_s)			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 KNm^{-3}
7.	Sieve analysis	Gravel	=	11%
		Sand	=	89%
8.	Direct shear test	c	=	6.1 kPa
		ø	=	31°
9.	Triaxial test	c	=	5.4 kPa
		ø	=	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 :

  $$\zeta = c + \sigma \tan \varnothing$$

- 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 neglible, 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 Sarma 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)	FOS
1.	A	63.6	37.50	1.07
2.	B	63.9	38.00	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. Gabions may be used for the construction of retaining structures. Thev 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.

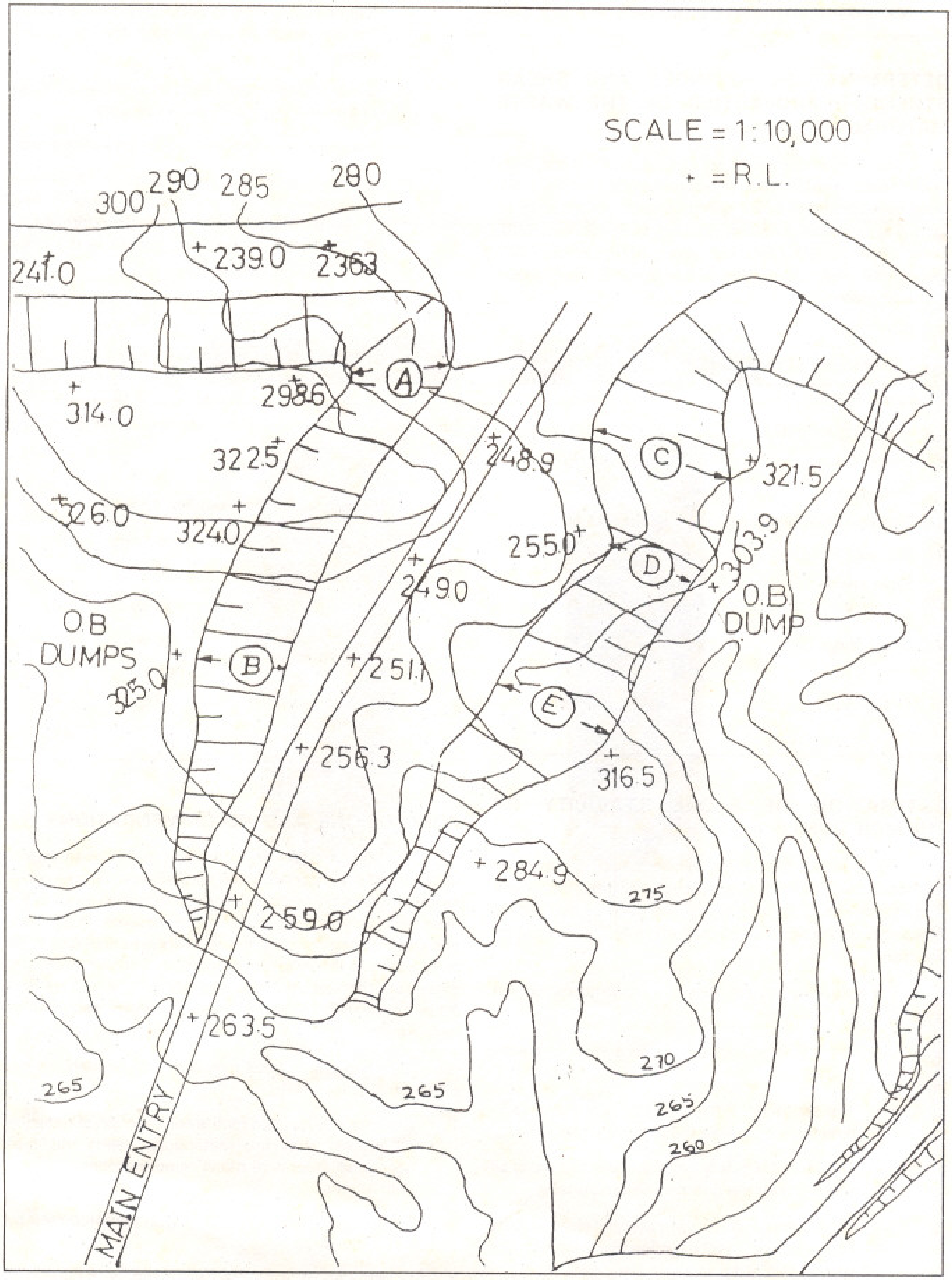

Fig. 1 : Plan of overburden dumps of an opencast coal mine with R. L. and ground contours

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).

6. Reduction of the dump slope angle and hydro-seeding of the slopes. Plantation assists the removal of water by transpiration, and the formation of a mat of roots can stabilize the surface of steep slopes (Chaulya & Singh, 1992 b; Akers, *et al*, 1974).

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 migh 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.

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