Requirement of Slope Monitoring & its principles

Introduction:

Dump slope and bench slope instability is one of the major concerns for the mining industry/mine owner, government regulators/statutory bodies, and environmental groups keeping in view the damage of surface infrastructure/loss of property, sustainability of mines, safety of personnel, economic, and environmental impacts. So, accurate assessment of the dump slope and bench slope stability is utmost importance for its proper and effective management.

The depths of open-pit mines have been increasing in the last few decades. This transformation generates a vast amount of waste rock material per unit mining area imposing a significant economic, social and environmental liability on the mine operators.

The waste dump material is accommodated as internal dumping within the mined-out area or external dumping outside the mined-out area but within the leasehold area of the mine. The external dumps are less efficient in land use and handling of dump material as compared to the internal dumps. However, it reduces the adverse impacts of the mining process and operation but increases the risk to the social and environmental domains, upon its failure.

The stability of bench slope and dump slope is affected by the combined effect of various parameters. These parameters are related to either manmade activities namely blasting, excavations, HEMM induced vibrations or naturally occurring phenomena like earthquake, presence of geological discontinuity within a mine (eg. faults) or in the vicinity of the mine area, development of tension crack near the top of a slope, rainwater seepage etc.

Dump slope and bench slope instability can be assessed by two ways: 1) using various analytical approaches (FEM, DEM and LEM) in prevalent Geo-mining conditions. 2) using various monitoring techniques (geodetic and non-geodetic). Further, accuracy of predicted movement of dump slope and bench slope surface using different analytical approaches remain a concern due to their own limitations in terms of detailed inputs required (especially geological and Geo-technical parameters) for better prediction of slope surface movement. Hence, dump slope and bench slope surface are required to be monitored during mining or post mining operation using suitable monitoring techniques to accurately assess any possible movement of dump slope and bench slope surface and to check the accuracy of predicted instability.

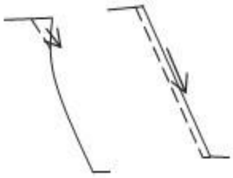
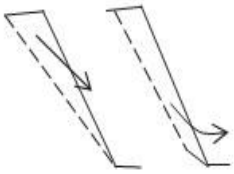
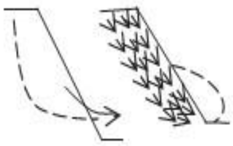
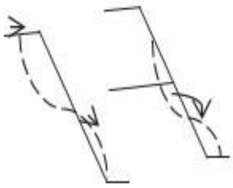
Failure Mode	Description	Illustrations	Key Factors Contributing to Instability	Stability Analysis Methods
Edge slumping (Crest slumping surface or silver failure)	Shallow failure involving down slope translation of material from the crest area parallel to the dump face. Failure does not extend up to the foundation		– Over steepening of the crest due to pressure of fine or metastable steep response angle of coarse rock blocks – Slacking of materials which form low permeability layers parallel to dump face – Heavy precipitation – Rapid rates of crest advancement – Most likely to occur in dumps constructed by end-dumping in thick lifts or by dozing materials over dump's crest	• Infinite slope analysis
Planar failure (Biplanar failure)	Sliding along a single plane of weakness within the embankment. May also involve shearing through the toe if the weakness plane does not slumping, but failure is generally deeper within the mass and result in substantially more crest break back		– Creation of a weakness plane which daylights on or parallels to the dump face possibly due to a zone of poor quality waste – High pore pressures within dump – Other factors similar to edge slumping	• Plane failure analysis • Biplanar or slab analysis • Wedge analysis
Rotational failure (Circular arc, creep)	Mass failure along a circular or curved surface within the dump material. Creep failure involving wide spread rotational slip characterized by bulging at the dump toe		– Homogeneous dump consisting of weak fine-grained materials – Excessive dump height in cohesive materials – High pore pressure within dump – Lack of lateral confinement support (ie, three-dimensional effect)	• Slip circle • Methods of slice • $Y=0$ method
Flow failure (Debris flow, flow slides)	Shallow failure involving slumping of saturated or partially saturated dump materials. Slump materials flow down the dump face in a semifluid state		– Concentrated surface flows discharging over the dump crest – Heavy precipitation, high infiltration, and/or development of a perched water table, resulting in saturation of near surface sump materials	• Infinite slope analysis with inclusion of seepage forces

Fig.1

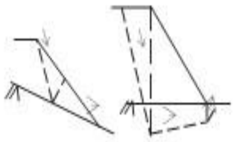
Failure Mode	Description	Illustration	Key Factor Contribution to Instability	Stability Analysis
Rotational failure (Circular arc)	Mass failure along a circular or curved failure surface, which extends into the foundation soils		– High pore pressure in foundation soils	• Slip circle • Methods of slices • $Y=0$ method • Bearing capacity analysis
Noncircular rotation (Base spreading)	Similar to rotational failure except that part of slip surface occurs along a weak base plane		– Occurrence of a weakness plane at the base of the dump or in the foundation soils – High pore pressures in foundation soils – Steep foundation slope – Adverse geological structure – Overfilled gullies	• Method of slices generalized for noncircular failure geometries • $Y=0$ method
Wedge failure (Multiple wedge, biplanar, base spreading, three-dimensional extended wedge)	Embankment fails as series of interactive blocks or wedges separated by planar discontinuities. Part of the failure surface occurs along a weak basal plane		– Occurrence of a weakness plane at the base of dump, or in the foundation soils – High pore pressure in foundation soils – Steep foundation slope – Adverse geological structure – Overfilled gullies	• Wedge analysis • Methods of slices generalized for noncircular failure geometries • $Y=0$ method • three-dimensional wedge analysis
Base translation (Planar sliding)	Sliding of bulk of dump as a rigid block along a weak base plane		– Occurrence of a weakness plane at the base of the dump, or in the foundation soils, or a discontinuity in the bedrock – High pore pressure in the foundation soils	• Plane failure analysis

Fig.2

Monitoring Techniques:

A common technique to determine slope stability is to monitor the small precursory movements which occur prior to collapse. Monitoring of slopes must be done in accordance with DGMS (Tech.) circular no. 2 Dhanbad dated 09.01.2020 and DGMS (Tech.) circular no. 3 Dhanbad of 2020 dated 16/01/2020.

Monitoring can be done using following measurement techniques:

1. Geodetic Measurement Technique
   It includes use of instruments such as Total Stations, Terrestrial Laser Scanners, GNSS (Global Navigation Satellite System) receivers.
2. Geotechnical Methods
   It includes use of instruments such as Extensometers, piezometers, tiltmeters and accelerometers.
3. Geophysical Methods
   It includes use of seismic surveys and electrical resistivity of soil.
4. Remote Sensing
   Remote Sensing often operates from aircraft or spacecraft platforms and uses electro magnetic waves emitted, reflected or diffracted by the sensed objects.
   It includes the use of instruments like radar, Lidar and Optical Camera

Monitoring Techniques

Slope System Monitoring	**Type**	**Advantages**	**Disadvantages**	**Range**	**Slope wall Coverage**	**Accuracy**
Visual Monitoring		-Production personnel can be involved. -No technology is required. -Inexpensive	-Labour intensive. -Limited to safe slope areas.	Limited (20-50m)	Small area	Not applicable
Surface Measurement	**Tension Crack Mapping**	Economical and simple to use	-Dangerous to install in unstable areas. -Measures displacement of discrete points.	Not applicable	Discrete points	$\pm$ 0.2% F.S.

			-Errors can be caused by long wire length due to sag or thermal expansion. -Alarm can be triggered by falling rocks or animals			
	Survey Network	-Automatic operation is available -Valuable for identifying long term displacement trend.	Suitable only for monitoring discrete points. -Prism installation is time consuming and dangerous on unstable slope. -Damaged prisms are difficult to replace on steep slope with no access. -Displacement data is affected by atmospheric variation in temperature and pressure. -Displacement data is affected by human error.	1500 m	Discrete points	± 5.0mm
	Global Positioning System (GPS)	Easy automation Higher accuracy Less labour intensive	-High cost of placing a permanent GPS receiver at each monitoring points. -Satellite signals can be obstructed by tall vegetation. -Usage for slope	4,000 to 20,000m	Discrete points	±10mm

			monitoring is still relatively new and expensive. -Slope surface can create signal multipath error.			
Subsurface Measurement	**Piezometers**	-Simple to install. - Function well in shallow and deep holes	-Careful handling is required for proper installation. -Requires periodic replacement of batteries. -The electronic units are susceptible to damage by lightning. -Borehole drilling for installation can be expensive. -Requires conversion of frequency reading to porepressure.	500 m	Discrete points	0.5mm
	Inclinometers	Subsurface displacement measurement of both shallow and deep-seated failure planes. Economical and simple touse	- Manual reading is time consuming and labour intensive. -If not properly installed, erroneous displacement readings may be recorded	100 m	Discrete points	$\pm$ 2.0mm
	Seismic Monitoring	-Provides early warning ofthe development of deformation -Detects displacement that cannot be identified by surface measurement.	Expensive to set-up.	2,000m	Discrete points	0.001mm
Remote Monitorin	**Time Domain**	-Rapid and Remote Monitoring is	Cable must be destroyed before	100 m	Discrete points	$\pm$0.5 mm

g Technologies	**Reflectometry (TDR)**	possible. -Slope displacement can be determined immediately. -Lower cost of installation. -Readings take minutes. -Can be installed at great depths.	displacement can be located. --Cannot measure deformation below the water surface because of changes in electrical properties of cable from water infiltration. -Cannot determine the magnitude and direction of slope movement.			
	Laser Scanner	-Prisms not required for slope monitoring. -Portable and can be moved around easily. -Continuous and automatic operation. -Large area monitoring Valuable for identifying long term displacement trend.	-Not commonly used for slope monitoring compared to radar monitoring. -Lower accuracy compared to radar monitoring. -Scan processing time is too great for effectiveness. -Accuracy impaired by differences in the reflectivity of the rock, the angle of the rock face, weather, vegetation. -Cannot provide early warning of failure.	2500 m	Large area	50mm
	Radar	-Continuous and automatic operation. -Operates in all-weather condition. -Geo-referencing is possible. -Sub-millimetre displacement measurement. -Large area and point monitoring.	-Expensive to procure and maintain. -Uncontrollable down-time.	1000m to 4000 m	Large area	$\pm$ 0.2mm

Table.1

In-addition, for comprehensive monitoring, satellite-based radar interferometry techniques may be added with above mentioned techniques.

General guidelines:

1. Points undergoing movement of 0mm to 2mm per day are monitored once per month.
2. Points undergoing movements of 2mm to 5mm per day are monitored once per week.
3. Points undergoing movements of 5mm to 10mm per day are monitored once every 2 days.
4. Points undergoing movements of 10mm to 50mm per day are monitored once per day.
5. Points undergoing movements of greater than 50mm per day require continuous observation.

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