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Influence of Structural Discontinuity on Slope Stability using Numerical Modelling and Sirovision

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Abstract

The rock mass consists of heterogeneous and anisotropic materials, with smaller and larger blocks of rock, and the presence of structural discontinuities is a significant concern. Characterising the rock mass is crucial for the success of engineering excavations in such areas. A detailed study of joints, their orientation, and discontinuities in the exposed rock mass is crucial as they greatly influence stability and fragmentation. Existing rock mass classifications like Rock Mass Rating (RMR) and Q-classification require various geological parameters and physico-mechanical properties of the rock. However, determining these parameters conventionally can be time-consuming, requiring careful on-site measurements. The number of opencast coal mines is increasing compared to underground mines due to shorter gestation periods, higher productivity, and quicker returns. However, opencast mining raises environmental concerns such as air and water pollution, solid waste management, land degradation, and socio-economic issues. Additionally, many opencast coal mines, regardless of size, are reaching greater depths, making analysing bench slopes and ultimate pit slope design crucial. Slope failure in these mines leads to production loss, additional costs for recovery and handling of failed material, pit dewatering, sometimes mine abandonment or premature closure, and loss of life. A study was conducted at Prakash Khani Opencast Mine – IV, Manuguru area, M/s The Singereni Company Collieries Limited (SCCL), to investigate the influence of structural discontinuities on slope stability. SIROVISION software was used to assess rock mass characterisation, while PLAXIS-2D software was employed to analyse the influence of structural discontinuities on slope stability. A comparative conclusion was drawn based on the results obtained from SIROVISION and PLAXIS-2D analyses. The study revealed that the RMR of the mine ranged from very poor to fair due to numerous discontinuities. It was also found that discontinuities in the slope decrease the Factor of Safety (FOS), indicating an impact on slope stability.

Keywords: *Discontinuities, Joint Properties, Plaxis, Sirovision, Slope Stability*

1.0 Introduction

The Indian economy heavily relies on mining. It is a significant sector that supplies raw materials to various industries. Regular advancements in mining technology are necessary to keep up with the growing demand for minerals. Innovative technologies enable workers to perform their tasks efficiently and safely. Opencast coal mines are becoming more prevalent than underground mines, thanks to their shorter waiting periods, higher productivity, and faster returns on investment.

Contrary to popular belief, opencast coal mining raises environmental issues such as solid waste management, land degradation, and socio-economic problems. Moreover,

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large and small-scale opencast mines are increasingly mining at greater depths, making it crucial to analyse bench slopes and establish ultimate pit slope designs. The design of bench slopes is of utmost importance, as slope failures result in decreased production, additional costs for recovering and handling failed materials, the need to dewater the pits, and sometimes forcing the early closure or abandonment of mines[1].

The advancement of slope stability analyses in geotechnical engineering has closely mirrored the progress in soil and rock mechanics. Slopes can be either naturally occurring or man-made. Historically, slope stability issues have arisen whenever human activities or natural forces have disrupted the delicate equilibrium of natural soil slopes. Additionally, the growing demand for engineered cut and fill slopes in construction projects has further emphasised the importance of comprehending analytical approaches, investigative tools, and stabilisation techniques to address slope stability challenges[2].

With the open pit mine being continuously explored and the slope becoming steep, the slope stability problem becomes more critical in the design. Slope stability is an essential consideration in the design. Thus, stabilising the slope is crucial for a mining project's success. The growing needs have been pushing the limits to which the mining industry has to lift itself to fulfil the demand. The effect can be seen in the methods of mining that have evolved over the years. The heavy machinery adopted for the extraction has been producing waste rocks, whose management is again of prime importance. The issues relating to the stability of these overburden dumps have been catching attention worldwide for some time, which is essential for the safe working in and around these monstrous structures and the restricted availability of land[3].

Maintaining pit slope angles that are as steep as possible is vital to reducing stripping (mining of waste rock), which directly affects the mining operation's economy. The design of the final pit limit is thus governed by the coal quality distribution, production costs, overall rock mass strength and stability[4]. Against this backdrop, there is a strong need for good slope design and management practices so that suitable corrective actions can be taken promptly to minimise slope failure[3].

The essential factors that cause instability in a slope leading to failure are gravitational force, rock stress and geotechnical characteristics, the strength of discontinuities and intact rock, pit geometry involving both slope angles and slope curvature, vibrations from blasting and seismic events, climatic conditions, time, the force due to seepage of water, erosion of the surface of the slopes due to flowing water, the sudden lowering of water due to a slope, and forces due to earthquakes. The effect of all these movements causes the soil to move from high points to low points. The most important of these forces is the component of gravity that acts in the direction of probable motion. The effects of flowing or seeping water are generally recognised as very important in stability problems, but often, these problems have not been adequately identified. It is a fact that seepage occurring within a soil mass causes seepage forces, which have a much more significant effect than is commonly realised[3,4].

Erosion on the surface of the slope may cause the removal of a certain weight of soil and may thus lead to increased stability as far as mass movement is concerned. On the other hand, erosion in the form of undercutting at the toe may increase the height of the slope or decrease the length of the incipient failure surface, thus decreasing the length and stability of the incipient failure surface. This increase in weight causes an increase in the shearing stresses, which may or may not be partly counteracted by the increase in the shearing strength. Whether or not the soil is of low permeability, practically no volume changes will be able to occur except at a slope rate, and despite the increase of the load, the strength increase may be inappreciable[5].

Slope instability accidents constitute a significant cause of deaths in surface mining operations in the United States. The Spokane Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) is researching to minimise fatalities related to slope failures[6]. The extent of jointing often determines the stability of rock masses. The volumetric joint count is a straightforward measure of jointing, considering all existing fractures and joints. It can be easily calculated using standard joint descriptions. For years, engineering geologists have found the volumetric joint count to be a valuable tool for characterising and classifying rock masses[7].

Understanding the behaviour and predicting the movement of rock masses play a critical role in ensuring the safety of mining and civil engineering projects. The fractures and gaps in the rocks can significantly influence their behaviour, and the overall structure of the rock mass is crucial for designing effective blasting techniques. Rockfalls pose a significant danger and can lead to fatal outcomes. Therefore, it is essential to accurately map the structure of rock masses to comprehend their potential behaviour. This understanding can positively impact safety and efficiency in engineering projects[8,9].

Mapping the structure of a rock mass is crucial for mining and civil engineering projects as it provides essential design information. This information includes descriptions of the observed rock mass structure, physico-mechanical properties of the rock mass, and inferences about its likely behaviour. Two critical applications of this mapping information are stability analysis and optimisation of blasting techniques based on predicted structure. To meet the needs of the mining and construction industries, a fast and reliable method for predicting rock mass structure systems is required. SIROVISION[10] is an innovative system that revolutionises mapping and analysing rock mass structures. It utilises three-dimensional (3D) imaging, which offers higher measurement and sampling accuracy than conventional mapping methods. SIROVISION[10] is commercial software that provides various benefits, including 3D imaging of mine pits, benches, and high walls from digital images, rapid and safe geological mapping, improved geotechnical assessment, and enhanced safety. By employing SIROVISION, mining and construction professionals can improve safety and productivity by accurately determining and analysing rock mass structure for geological and geotechnical assessment[10].

Numerical models have demonstrated their ability to provide a comprehensive understanding of the complex behaviour of geotechnical systems. With Plaxis 2D[11], engineers and geotechnical professionals can perform advanced analyses to assess the stability of open pit slopes and evaluate the safety of structures. Plaxis enables a more precise assessment of factors influencing slope stability by considering various material properties and incorporating realistic boundary conditions. By utilising Plaxis for numerical modelling, professionals can gain valuable insights into the behaviour of soil, rock, and structural support systems. This enhanced understanding allows for more informed decision-making and improved design of geotechnical structures[12]. Hence, in this study, the discontinuity features were determined using sirovision software and the influence of discontinuity on slope failure was determined using Plaxis software.

2.0 Investigations

2.1 Case Study

An experimental study was conducted in Prakash Khani Opencast Mine – IV (PKOC-IV), Manuguru area of M/s

Figure 1. Prakash Khani Opencast mine –IV, Manuguru area of M/s The Singereni Company Collieries Limited (The SCCL).

Figure 2. Mine benches with features of discontinuities.

The Singereni Company Collieries Limited (The SCCL). There are 8 benches in the mine; 5 benches are overburden, and 3 benches are in coal, as shown in Figures 1 and 2. The images are captured from all the benches based on the accessibility of the bench.

Prakasham Khani Open cast mine is a very extensive, mechanised mine. The block is located between latitude 17˚ 55' 34" and 17˚ 59' 11", an East longitude 80˚ 43' 57" and 80˚ 47' 27" in the survey of India Topo sheets 65 C/9 and 65 C/13. It was formed by merging PKOC II, MNG III, and PKOC IV Projects into one project named "Prakasham Khani Open Cast" mine.

2.2 Capturing Images for Joint Analysis

The following steps were adopted to capture the photographs depending upon the georeferencing used[10]: a) Selecting the camera and lens according to the bench height specified in the SIROVISION software. In the Manuguru area, the bench height is approximately 13 to 15m, so a Nikon D200 camera and 35mm lens were used. b) Selecting the area of the wall to photograph – It was randomly selected based on the visibility of discontinuities. c) The distance from the approximate camera positions to the rock face was established using a GPS. d) The layout distance between the rockface and baseline between cameras, preferably at 1:6 to 1:8, as shown in Figure 3. is established e) Control Points are placed on the field (spray paint is used to mark the control points in the face). f) Compass, GPS, and handheld devices measure the coordinates, reduced level, and direction. g) The camera position was first set on the left side of the bench face, and the location was marked (to measure baseline and 's') as shown in Figure 3. The camera height was measured using the total station from the mine. h) The left-hand photograph was captured, and an overlap of 30-50 % was planned for the right-hand capture. i) The field notes were recorded about the photographs captured (GPS Position of two camera positions, image number in the camera, baseline distance are noted) j) Procedure was repeated for right-hand photograph capture, keeping

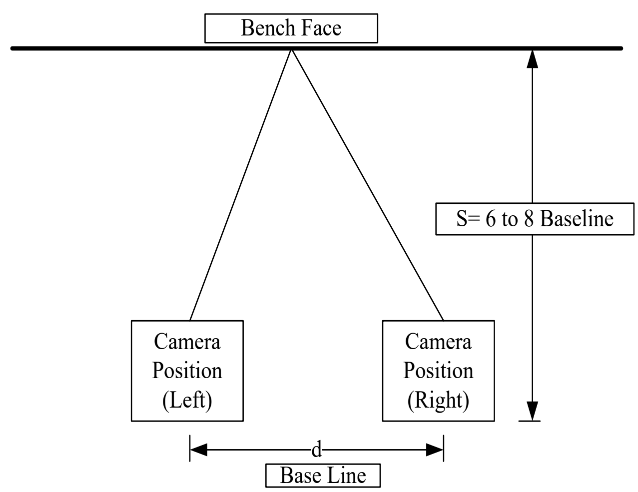

Figure 3. General layout for camera position[10].

in mind overlapping k) The acquired right-hand images of the same coverage of the rock face were obtained in the corresponding left-sided images, l) A Bushnell laser pro was used as a laser rangefinder. The most common method is to measure the distance to the closest point on the face and the base of the slope[10].

2.3 Sirovision

After the images are captured in the field, they are downloaded into the computer and converted into TIFF (Tag Image File Format) files, and then they are processed in SIROVISION.

2.3.1 Creating the 3D Image using Siro3D

The left and right photographs were captured in different bench locations, as shown in Figure 4 and Figure 5, respectively. A typical 3D image is created and is shown in Figure 6.

Figure 4. Left image.

Figure 5. Right image.

Figure 6. 3D image generated by Siro3D.

2.3.2 Processing the 3D Image using Sirojoint

The 3D image was analysed using Sirojoint, as shown in Figure 7, to generate necessary data about discontinuities like spacing, orientation, etc. The histogram of spacing, the orientation of discontinuities, and the spherical projection of discontinuities from Sirojoint are shown in Figures 8, 9, and 10, respectively. The joint properties like joint orientation (Dip of the Discontinuity and Dip Direction of the Discontinuity) and joint Spacing of various mine locations are obtained and given in Table 1. The properties determined from the laboratory, Sirovision

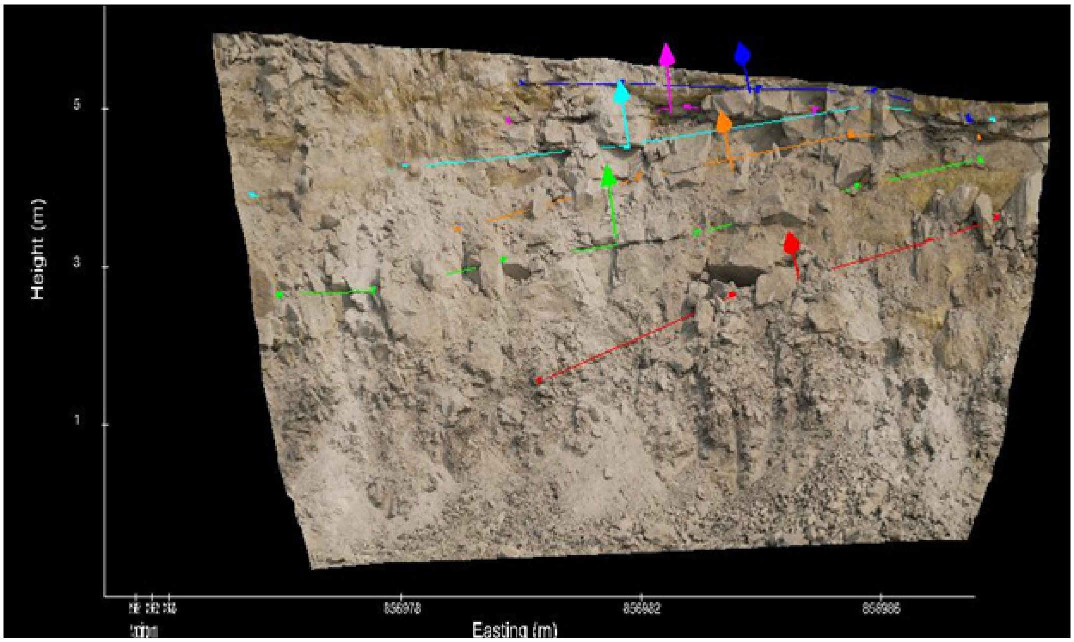

Figure 7. 3D image processed in Sirojoint.

Figure 8. Histogram of spacin of discontinuities.

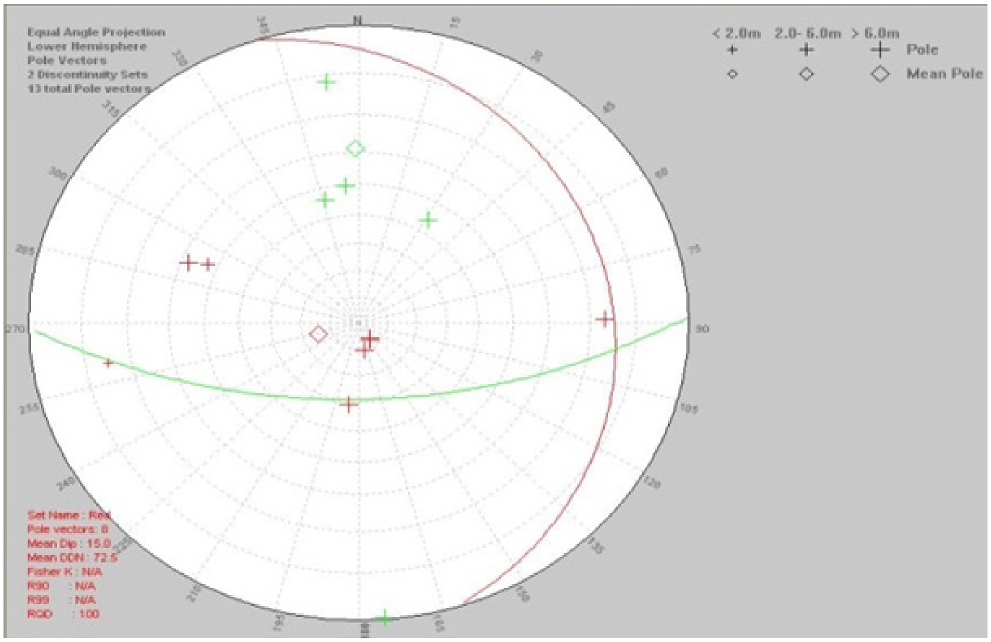

Figure 9. Orientation of discontinuities.

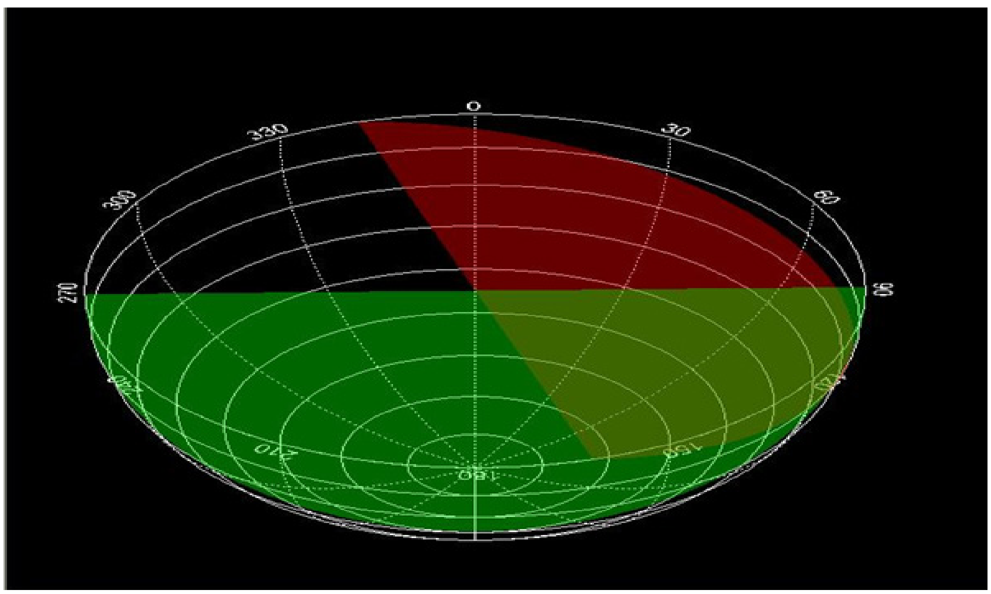

Figure 10. 3D Spherical projection of discontinuities distribution.

and field studies are used to calculate the RMR (Rock Mass Rating)[13] as shown in Table 1.

2.3 Laboratory Analysis

The sandstone samples are collected from various mine locations, and the following physicomechanical properties were determined per the suggested methods of ISRM (*International Society for Rock Mechanics,* 1978)[14] standards.

2.3.1 Density

Density is an essential measure that tells us how much mass is squeezed into a particular volume of material. The density of sandstone was determined in a laboratory

Table 1. RMR for different bench locations

Bench	Location	UCS (MPa)	RQD	Mean Spacing (m)	Condition of the Discontinuities	Ground Water Condition	Mean Dip (Degree)	RMR
1	1	72.87	44	3.376	Slicken sided surface	Wet	15	Fair
		7	8	20	10	7	-5	47
	2	72.87	44	1.072	Slicken sided surface	Wet	15.6	Fair
		7	8	15	10	7	-5	42
2	1	120.64	63	0.473	Slicken sided surface	Wet	17.9	Fair
		12	13	10	10	7	-5	47
	2	120.64	63	2.58	Slicken sided surface	Wet	7.7	Fair
		12	13	20	10	7	-5	57
	3	120.64	63	1.265	Slicken sided surface	Wet	39.3	Poor
		12	13	15	10	7	-25	32
3	1	72.87	78	0.610	Slicken sided surface	Wet	3.1	Fair
		7	17	15	10	7	-5	51
	2	72.87	78	2.274	Slicken sided surface	Wet	21.8	Poor
		7	17	20	10	7	-25	36
	3	72.87	78	0.508	Slicken sided surface	Wet	5.1	Fair
		7	17	10	10	7	-5	46
	4	72.87	78	1.253	Slicken sided surface	Wet	16.0	Fair
		7	17	15	10	7	-5	51
	5	72.87	78	3.234	Slicken sided surface	Wet	9.5	Fair
		7	17	20	10	7	-5	56
	6	72.87	78	1.243	Slicken sided surface	Wet	39.5	Poor
		7	17	15	10	7	-25	31

4	1	147.67	78	0.735	Slicken sided surface	Wet	29.5	Poor
		12	17	15	10	7	-25	36
	2	147.67	78	4.546	Slicken sided surface	Wet	21.1	Fair
		12	17	20	10	7	-25	41
	3	147.67	78	0.684	Slicken sided surface	Wet	26.2	Poor
		12	17	15	10	7	-25	36
5	1	120.64	50	0.572	Slicken sided surface	Wet	3	Fair
		12	8	10	10	7	-5	42
	2	120.64	50	1.030	Slicken sided surface	Wet	9.9	Fair
		12	8	15	10	7	-5	47
	3	120.64	50	0.531	Slicken sided surface	Wet	14.7	Fair
		12	8	10	10	7	-5	42
	4	120.64	50	1.738	Slicken sided surface	Wet	20.5	Poor
		12	8	15	10	7	-25	27
	5	120.64	50	0.783	Slicken sided surface	Wet	25.3	Poor
		12	8	15	10	7	-25	27
6	1	96.3	63	0.929	Slicken sided surface	Wet	49	Very poor
		7	13	15	10	7	-50	2
	2	96.3	63	1.255	Slicken sided surface	Wet	30.3	Poor
		7	13	15	10	7	-25	27
7	1	96.3	76	1.143	Slicken sided surface	Wet	36.9	Fair
		7	17	15	10	7	-25	31
	2	96.3	76	2.006	Slicken sided surface	Wet	29.5	Poor
		7	17	20	10	7	-25	34
	3	72.87	76	2.957	Slicken sided surface	Wet	40.5	Poor
		7	17	20	10	7	-25	34
	4	72.87	76	0.596	Slicken sided surface	Wet	17.5	Fair
		7	17	10	10	7	-5	46

7	5	72.87	76	0.938	Slicken sided surface	Wet	30.4	Poor
		7	17	15	10	7	-25	31
	6	72.87	76	0.179	Slicken sided surface	Wet	17.7	Fair
		7	17	8	10	7	-5	44

by the instantaneous water immersion method as per ISRM (*International Society for Rock Mechanics*, 1978)[14] standards. It is found to be 2.323 Kg/m^3.

2.3.2 Uni-Axial Compressive Strength

Compressive strength refers to the capacity of a material to withstand compressive forces that act in an axial direction. The uni-axial compressive strength of the sandstone sample was determined using the uni-axial testing machine as per ISRM (*International Society for Rock Mechanics*, 1978)[14] standards. In the case of a sandstone sample, its uniaxial compressive strength falls within the range of 95 MPa.

2.4 Numerical Modelling

2.4.1 PlAXIS 2D

After obtaining the physico-mechanical properties, the 2D (Dimensional) geometric model is simulated in the PLAXIS 2D based on the bench height, width, slope angle, and ultimate pit slope and the mesh is generated for the same as shown in Figures 11-12. The 2D simulated model is developed with earth co-efficient pressure (K), very fine mesh size and the standard fixities are applied, i.e. along the 'x' and 'y' direction, as shown in Figure 13. The physico-mechanical properties and joint properties considered for Modelling are shown in Tables 2 and 3. The Young's Modulus, Poisson's Ratio, Modulus of rigidity, Cohesion, dilatancy angle and friction angle are based on the results collected from the mines PKOC-IV, The SCCL, Manuguru.

The model is subjected to loading conditions considering the highest operating dumper in the bench, i.e., 2 times the 60T dumper, and the self-weight of the bench, i.e., 200 kN. The simulated model is deformed, and the effective stress developed is obtained, as shown in Figure 14.

Table 2. Physico-mechanical properties of sandstone sample obtained from PKOC-IV, the SCCL, Manuguru

Sl.No.	Physico-mechanical Properties of Sandstone		Range
	Uni-axial Compressive Strength (UCS)	(MPa)	95
	Tensile Strength	(MPa)	6.5
	Young's Modulus	(GPa)	5
	Modulus of Rigidity	(GPa)	0.7
	Cohesion	(MPa)	2.89
	Co-efficient of friction		30^0
	Dialactent Angle		30^0
	Density	(KN/m^2)	23.23

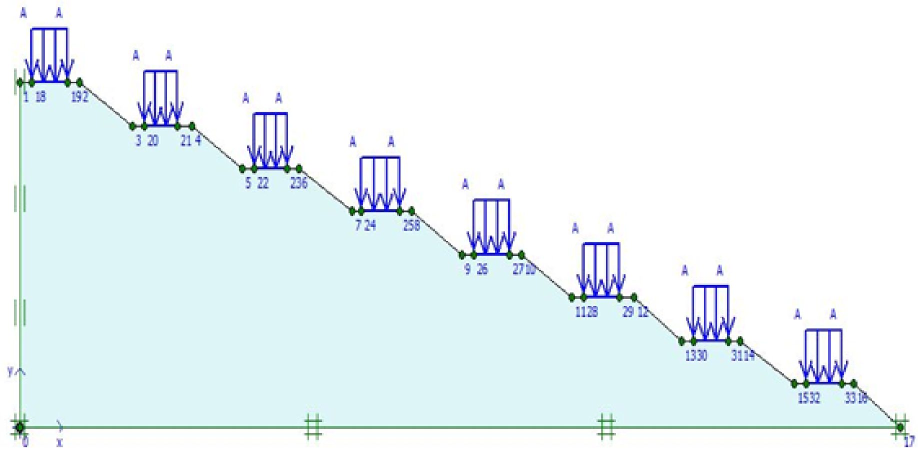

Figure 11. Geometric 2D model.

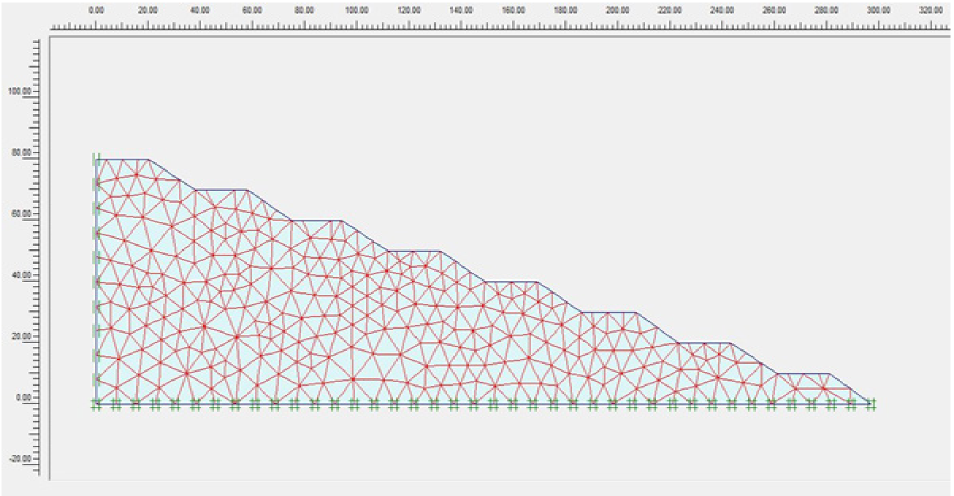

Figure 12. Mesh generated model.

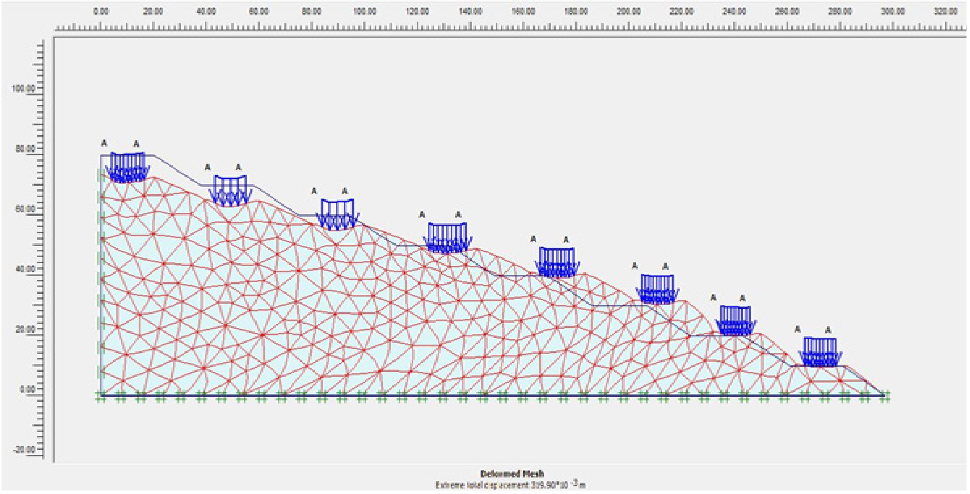

Figure 13. Deformed mesh.

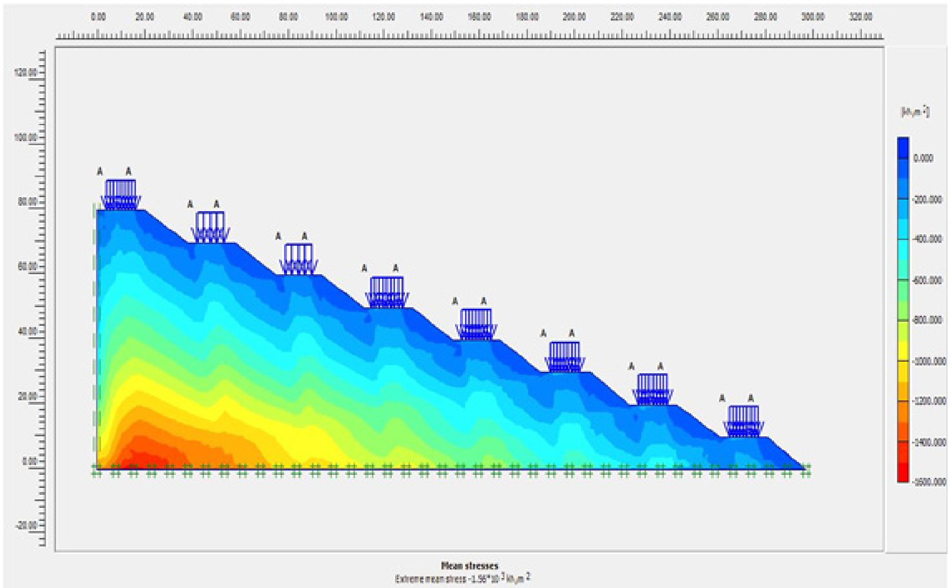

Figure 14. Effective stress developed in the model.

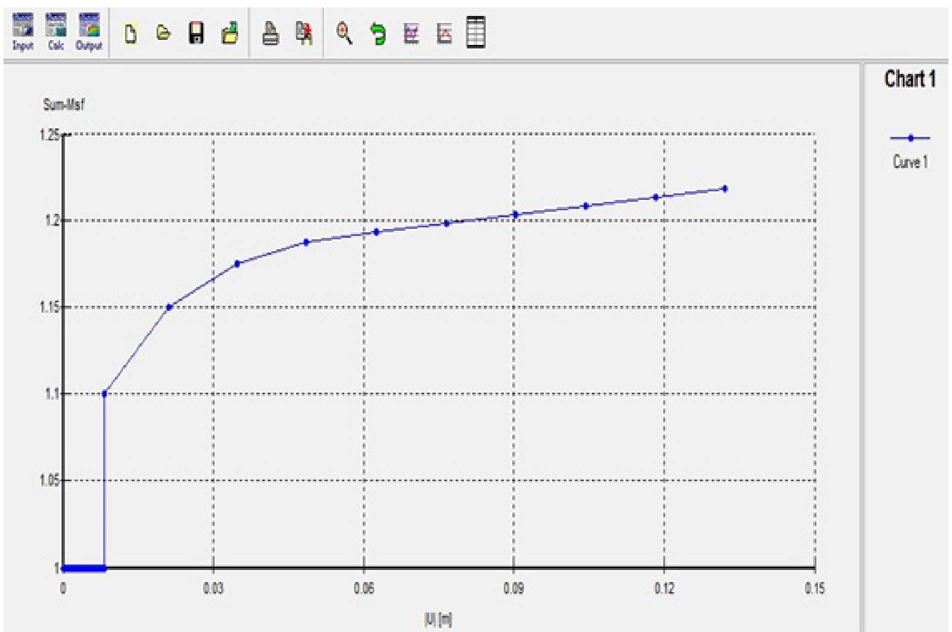

Figure 15. Chart showing factor of safety versus total displacement.

The parametric variation is considered in the simulation of slope angle, bench height, bench width and joint orientation on slope stability. Initially, an ideal bench was created without any discontinuity in the slope with bench height varying from 10m to 20m, bench width varying from 20m to 30m and slope angle varying from 30° to 90°. The factor of safety obtained for the same is shown in Figure 15. The influence of bench height and width on slope stability was obtained by varying bench height to bench width ratios from 10-20, 15-25, and 20-30, i.e., 2, 1.66, and 1.5, respectively. The bench height to bench width ratio, 15:25 (1.66), simulates the condition of the Prakash Khani Opencast mine –IV, Manuguru area, M/s The Singereni Company Collieries Limited (The SCCL).

Table 3. Joint properties used in plaxis 2D modelling

Cohesion (Mpa)	Dip of Discontinuity	Dip Direction
0.1	0^0-90^0	90^0

Two conditions were considered to study the influence of discontinuity angle on the bench parameters: i. A single set of discontinuity (who's spacing is less than 0.5m), where its dip of the discontinuity varies from 0-90° with an increment of 10° ii. Two sets of discontinuities (who's spacing is less than 0.5m), where the dip of the discontinuity varies from 0-90 ° with an increment of 10°.

3.0 Results and Discussions

3.1 Results Obtained from SIROVISION

The RMR rating suggests that the rock sample has varying qualities of very poor, poor, and fair, and values are given in Table 2.1. As the dip of the discontinuity and sets of discontinuities increase in the rock mass, the RMR rating decreases due to the presence of discontinuities, which also decreases the strength of the rock.

3.2 Results Obtained from Numerical Modelling

3.2.1 Influence of Bench Height and Bench Width on FOS

The influence of slope angle on FOS for different bench height and width combinations is shown in Figure 16. It was observed that as the slope angle increases, the FOS decreases nonlinearly for different bench height and bench width combinations due to a decrease in cohesion and an increase in the self-weight of the block.

3.2.2 Influence of Bench Slope Angle on FOS

The influence of slope angle on FOS for different discontinuity angles and different bench height and width combinations is shown in Figure 17. As it was observed, for a given discontinuity angle, as the slope angle increases, the factor of safety decreases nonlinearly. The safety factor reaches zero for steeper discontinuity and slope angles. The safety factor is much lower than ideal bench characteristics due to a discontinuity in the face.

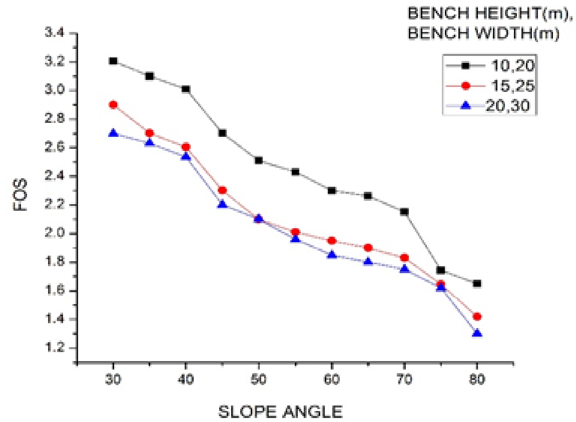

Figure 16. Influence of slope angle on FOS for different bench height and bench width combination.

The influence of slope angle on FOS for different discontinuity angles (two sets of discontinuities) and different bench height and width combinations is shown in Figure 18. As observed, the safety factor decreases non-lineally as the slope angle increases for a given discontinuity angle. The safety factor reaches zero for steeper discontinuity and slope angles.

The influence of slope angle on FOS for different bench height and bench width combinations is shown in Figure 16. As the slope angle increases, with an increase in bench height and bench width, the factor of safety decreases nonlinearly.

The influence of slope angle on FOS for different discontinuity angles and different bench height and width combinations is shown in Figure 17. As observed, for a given discontinuity angle, as the slope angle increases, the safety factor decreases nonlinearly in the case of each discontinuity angle.

The influence of slope angle on FOS for different discontinuity angles and different bench height and width combinations is shown in Figure 18. As observed, for a given discontinuity angle (two sets of discontinuities), as the slope angle increases, the safety factor decreases nonlinearly in the case of each discontinuity angle.

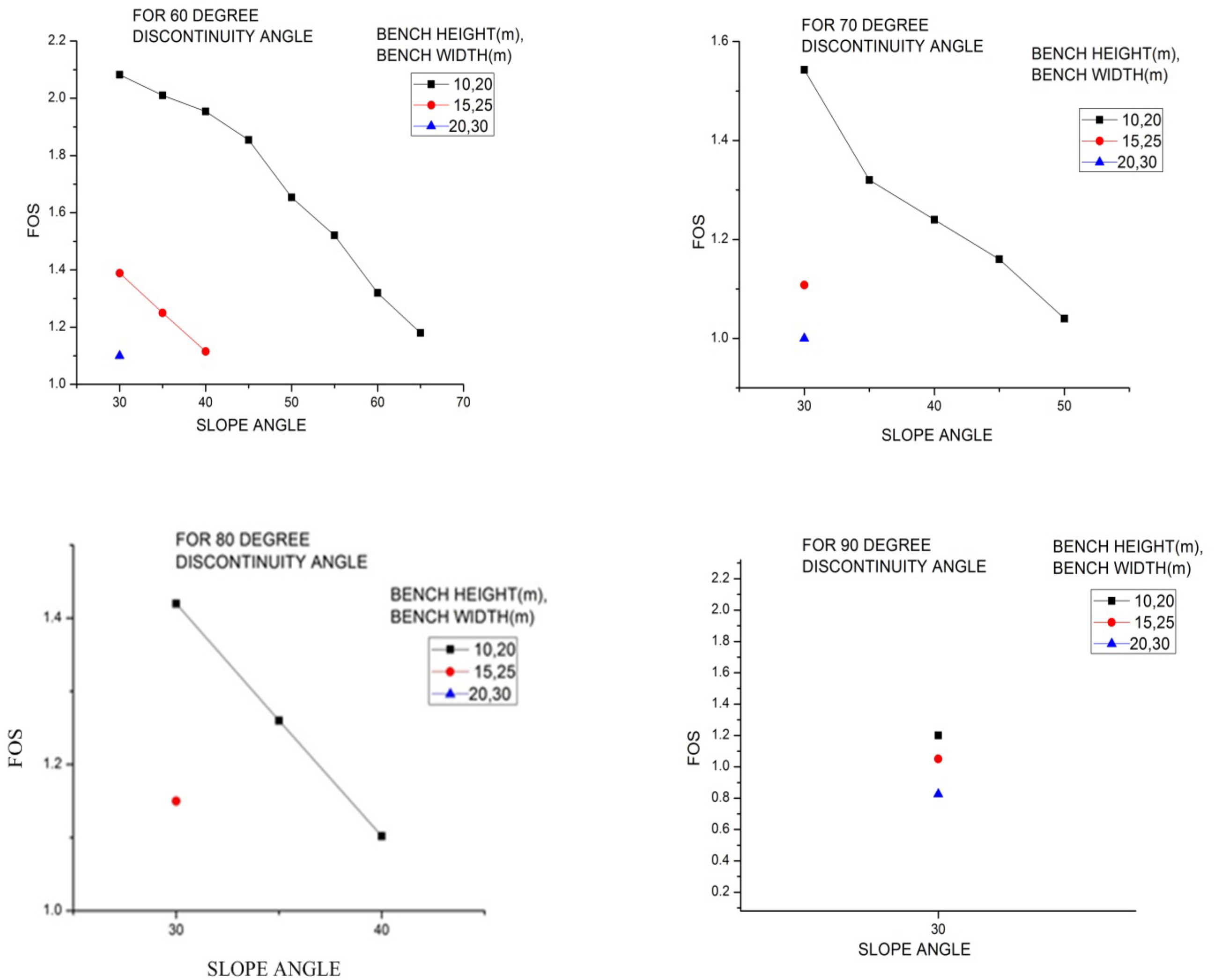

Figure 17. Influence of slope angle on FOS for different discontinuity angle and different bench height and bench width combination.

3.2.3 Influence of Discontinuity Angle and Sets of Discontinuities on FOS

The influence of discontinuity angle on FOS for different slope angles is shown in Figure 19. It was observed that, as the discontinuity angle increases, the factor of safety decreases nonlinearly for different slope angles, bench height, bench width and overall slope.

The influence of discontinuity angles (Two sets of discontinuities) on FOS for different slope angles is shown in Figure 20. As the discontinuity angle (two sets of discontinuities) increases, the safety factor decreases nonlinearly for different slope angles, bench height, bench width and ultimate pit slopes. The safety factor is much lower compared to ideal bench characteristics and single set of discontinuity bench characteristics due to two sets of discontinuities in the face.

Considering the design stability, the FOS less than 1 is not considered in the graph plot.

The influence of discontinuity angle on FOS for different slope angles is shown in Figure 19. It was observed that, as the discontinuity angle increases, the factor of safety decreases nonlinearly for different slope angles, bench height, bench width and overall slope.

The influence of discontinuity angle on FOS for different slope angles is shown in Figure 20. As the

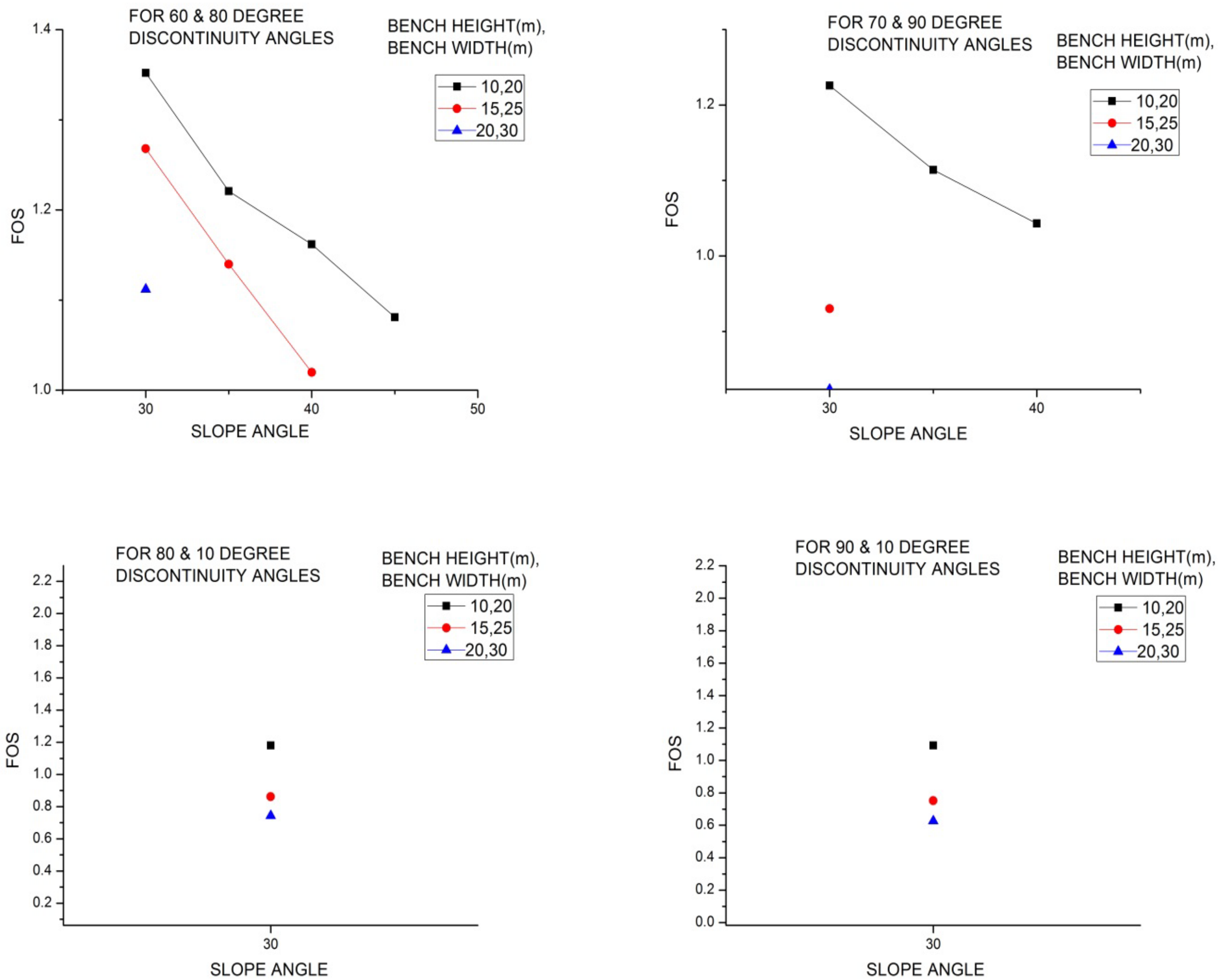

Figure 18. Influence of slope angle on FOS for different discontinuity angles and different bench height and bench width combination.

discontinuity angles (two sets of discontinuities) increase, the safety factor decreases nonlinearly for different slope angles, bench height, bench width and overall slope.

4.0 Conclusion

In the Manuguru area of the SCCL, the strata are associated with discontinuities. SIROVISION software was used to determine the joint properties in the rock mass, like joint spacing and orientation. Rock mass characterisation was done, where the rock mass rating ranged from very poor to fair. Numerical modelling was used to analyse the slope stability. The ultimate pit depth varied from 80m to 160m, the slope angle from 30^0- 80^0, and the ultimate pit slope varying from 16^0-38^0 were considered.

In the case of ideal benches, i.e. the slopes without discontinuities have higher FOS, i.e., 3.205 - 1.3. As the bench characteristics like height, width, slope angle and ultimate slope angle increase, FOS decreases. As the bench height to bench width ratio decreases, the FOS decreases, i.e. reduction by 13.5% for 15m to 25m and 18% for 20m to 30m, when compared with the 10m to 20m ratio. In the presence of a single set of discontinuity in the slope, as the bench height and bench width increases, there is a reduction in FOS by 28% for the 15m to 25m ratio and 45% for the 20m to 30m ratio, when

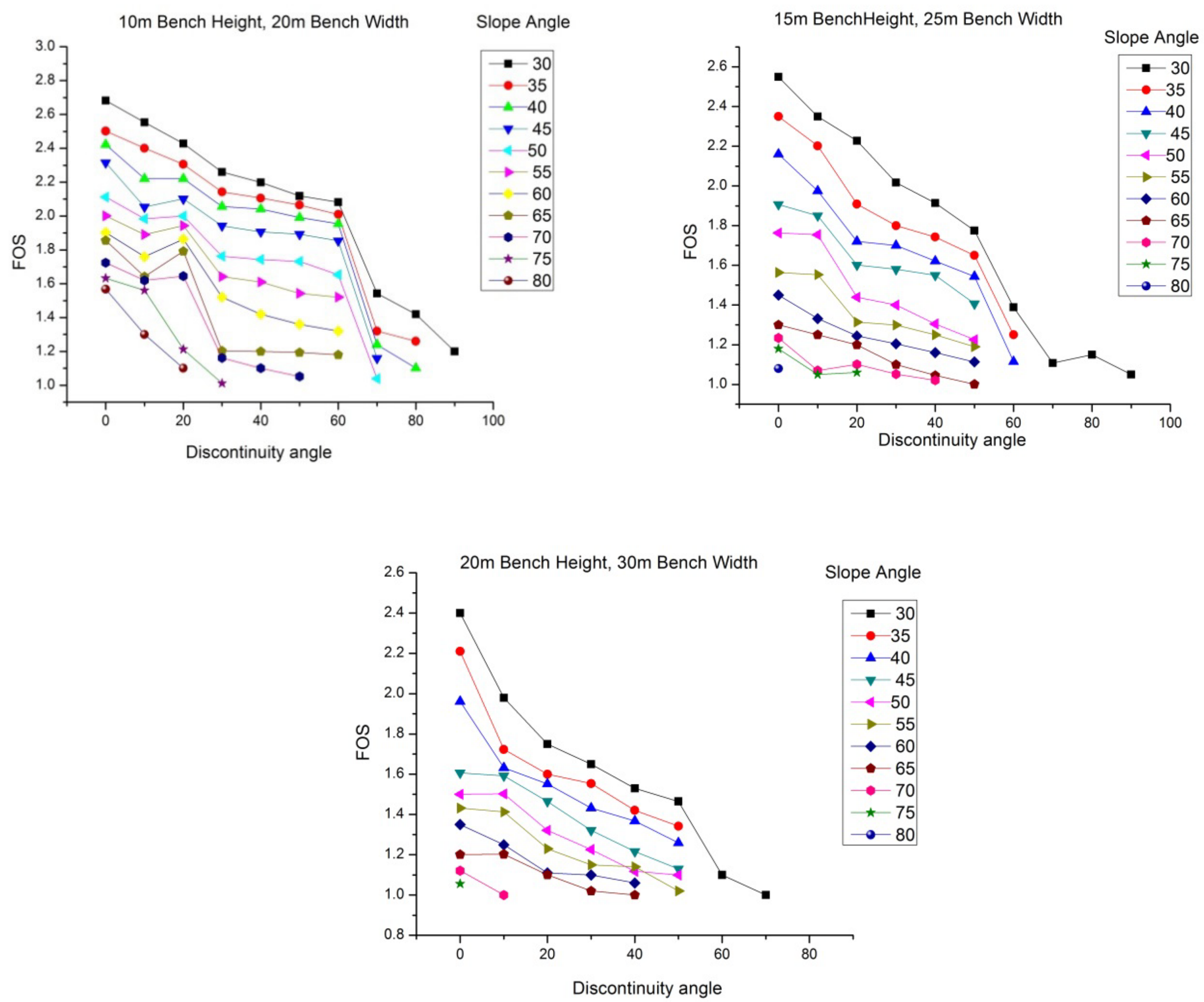

Figure 19. Influence of discontinuity angle on FOS for different slope angles.

compared with the 10m to 20m. In the presence of two sets of discontinuities in the slope, as the bench height and bench width increases, there is a reduction in FOS by 27% for the 15m to 25m ratio and 42% for the 20m to 30m ratio, when compared with the 10m to 20m. But when the single set of discontinuities is compared with two sets of discontinuities, the FOS of the slope with two sets of discontinuities is less by 16.9% from the single set of discontinuities. As the slope angle, bench height, bench width, ultimate slope angle, discontinuity angle and sets of discontinuity increase, the FOS of the bench decreases, i.e. in the case of a single set of discontinuity as bench height, bench width, and slope angle increases, with an increase in discontinuity the FOS reduces to 2.683 to <1 and in case of two sets of discontinuity as bench height, bench width, and slope angle increases, with an increase in discontinuity angle and sets of discontinuities, the FOS reduces to 2.268 to <1. This indicates that as the discontinuity angle and sets of discontinuities increase, the FOS of the slope is reduced. In RMR, joint orientation, i.e. dip of the discontinuity, varies from 3 to 49 degrees. As the dip of the discontinuity increases, the RMR of the location decreases. This indicates that the stability of the location decreases. Similarly, in the case of numerical Modelling, as the discontinuity angle and sets of discontinuities increase, the factor of safety or stability of the slope decreases. Based on the study, it is found that the discontinuity is also an important parameter that affects the slope stability of an opencast mine.

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