Slope Stability Analysis of Nkran Pit at Asanko Gold Mine, Ghana

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ABSTRACT: The West Wall of Nkran Pit Mine is vulnerable to slope instability, mostly due to mining activities. Detailed failure analysis of the discontinuity data of the selected slope was performed using the Dips (6.0) software. The study has shown the likelihood of planar failure, wedge failure, flexural toppling failure and direct toppling failure occurring per the slope angle design of 70°. When the slope angle was increased by 5° and 10°, there were percentage increases in planar, wedge, flexural toppling and direct toppling failure of (1.86 and 7.45)%, (1.23 and 2.81)%, (0.62 and 0.62)% and (0.60 and 1.70)% respectively. It has been recommended that flattening or reducing slope angle could be done as it reduces the weight of material which in turn improves the stability of the slope and also controlled blasting should be employed to minimise excessive damage to the walls.

Slope stability evaluation is executed to assess the secure design of a human-made slope or natural slope and its equilibrium situations. Slope stability is the resistance of inclined surface to failure by sliding or collapsing (Kliche, 1999). For an open pit mine, an excavation is made into the earth for the extraction of valuable rocks and minerals. This excavation is cut in slopes and benches. The slope and bench layout are designed to produce an overall slope angle that is stable. For design, it is needed to be acquainted with and to recognise the numerous approaches wherein slopes in rocks can fail. Many mining companies have been shut down due to their inability to assess their slopes. In 1960, a coal mine at Coalbrook in South Africa collapsed with the loss of 432 lives (Salamon and Munro, 1967).

Slope instability affects the operations of open pit mines resulting in loss of lives and machinery as well as slope design changes. Instability problems emerge due to disturbed pressure state, the presence of discontinuities and further stress load from blasting. These factors, coupled with uncontrolled pore water pressure, lead to pit slope failures. The Western Pit wall of the Nkran Pit in Asanko Gold Mine is vulnerable to slope instability due to mining activities. This problem arises owing to natural factors as well as human-made factors.

The stability of a pit slope is commonly evaluated using numerical modelling and empirical rock mass systems. While numerical modelling simulates the effect of stress distribution in the slope and displacements on its behaviour, the rock mass classification systems are often used for initial assessment of the rock mass behaviour. The well-known rock mass classification systems applicable to slope stability include the Slope Mass Rating, the Slope Rock Mass Rating, Chinese Slope Mass Rating, the Geological Strength Index, the Rock Quality Designation and the Rock Mass Rating (Basahel and Mitri 2017; Bieniawski 1989; Deere 1964; Pantelidis 2009).

The purpose of this study is to assess the current stability state of the Western Pit wall of the Nkran Pit in Asanko Gold Mine in order to improve the safety of the Pit. The objectives of this paper is to determine the possible modes of failure that can occur at the West Wall of the Nkran Pit, to evaluate the possibility and effect of increasing the Nkran West Wall slope angle by 5° and 10° from 70° and find possible solutions in controlling or preventing slope failures to stabilise the Pit wall. A kinematic analysis was performed.

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METHODS AND MATERIALS

Failures, which occur in slopes, are controlled by the presence of discontinuities such as fault bedding planes, joints, and shear zones. The orientation as well as how they intersect each structure can cause slope failure. Therefore, it is imperative that all the types of structures are mapped out to see how they interrupt and affect the slope to help prevent slope failure.

Window mapping was done along discontinuities present on the slope face, and this helped to demarcate the area of interest. Areas demarcated included highly jointed and faulted zones. The size of the window used was 30 m in length. The ideal locations considered for windows were the corners since they provide a 3D view of the rock mass. A window covered only a single rock type. This was done to check the accuracy of the geological map for the area and make amendments where necessary. Careful records of the site location, coordinates, and face orientation were recorded on a log sheet as shown in Figure 1 was used for the recordings of window mapping data on the field. These were used to orient the data collected spatially.

The GPS was used to take coordinates for each structure that was mapped such as joints, faults, and shear zones. Dip and dip direction were mapped using the compass. The joint spacing, joint openings, and infill materials were measured with the measuring tape. Surface roughness was also noted.

The dip and dip direction gave the orientation of the structure so that in areas where kinematic failures were possible, slope angles that would incorporate the mean orientation of the structure could be designated.

Analysis of the Nkran West Wall was assessed using DIPS 6.0 Rockscience to determine the possible modes of failure that can occur and the possibility and effect of increasing the west slope angle by 5° and 10° from 70°.

Using the field geotechnical mapping data depicting orientation of structural defects   to plot a stereonet, the   analyses for planar, wedge and toppling failures were done on each plot using a mean frictional angle of 30° and dip direction of 130° per design at the Nkran West Wall.

RESULTS AND DISCUSSION

The data used in the analysis were measurements taken from Pit wall mapping at the western cut back part of the Nkran Pit. The rock face above the current floor of the existing Pit has a dip of 70° degrees and a

dip direction of 130° degrees. A total of 161 data points were picked. Figure 1 shows qualitative chart of structures as well as the dataset that was used to perform the qualitative assessment. The density pole concentration lying with each failure is also shown in Figure 2.
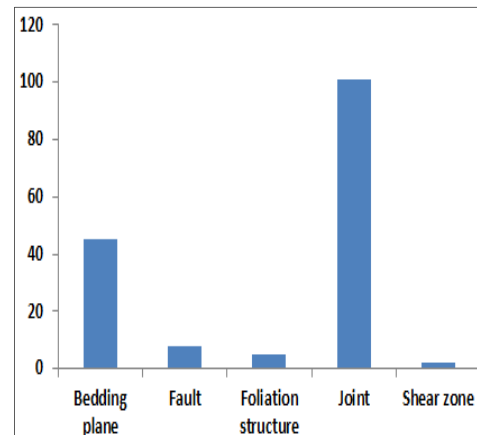

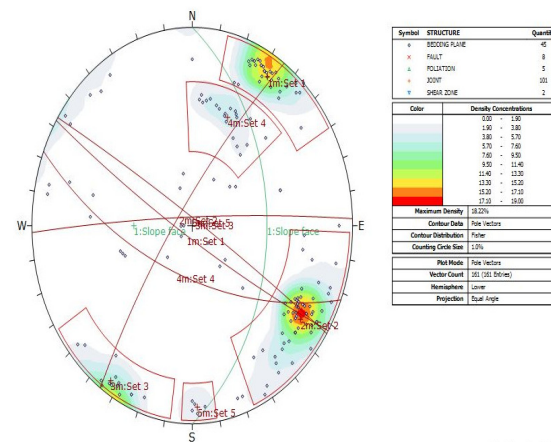**Fig. 1:** Qualitative Chart of Structures

Fig. 2: Density Pole Concentration

This shows the planes from the poles and the data sets. These help to obtain the mean orientation of the data.

Planar Failure Analysis: A stereonet analysis was performed for planar failure to indicate the unstable zones and the joint sets that have the same property and behaviour. The extent of concentration of the joint sets have been displayed beside the stereonet in a legend, and frictional cone and a daylight envelope, and planes showing the slope face was plotted during the analysis.

The crescent shape formed by the daylight envelope and the cone of friction encloses the region of planar sliding (unstable zone) and joints found at that region represent joints which fell at the critical zone.

For this type of failure to occur, the discontinuities must daylight (exposed) on the slope and be parallel or near parallel to the slope face, at an angle greater than the angle of friction of the slope. A kinematic analyses result of a planar failure of the Nkran West Wall with a slope angle of 70° and 80° are as shown in Figures 3 and 4 respectively.
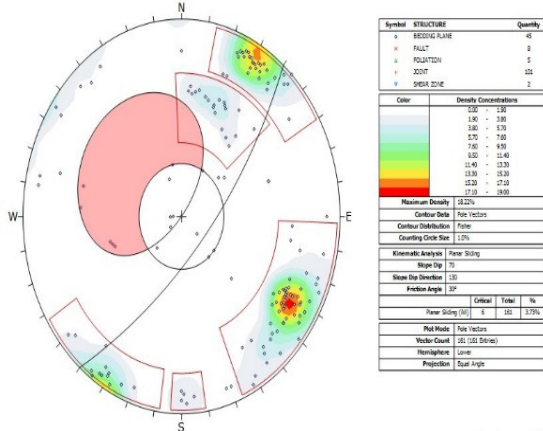

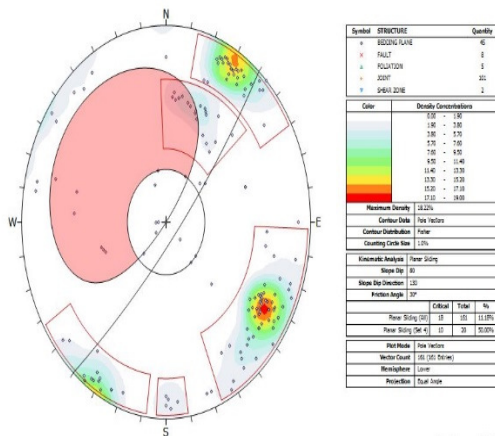**Fig.3:** Planar Analysis of the Nkran West Wall at **70°**

Fig.4: Planar Analysis of the Nkran West Wall at 80°

Table 1 shows for the kinematic analysis of planar failure.

Table 1: Kinematic Analysis of Planar Failure

Pit Area	Slope Dip Direction	Slope Angle	Percentage of Total Plane Failure
Nkran West Wall	130°	70°	3.73%
Nkran West Wall	130°	75°	5.59%
Nkran West Wall	130°	80°	11.18%

Wedge Failure Analysis: For wedge failure to occur, the point of intersection between two discontinuities should be enclosed in the plane of friction cone and daylight less than the slope face.
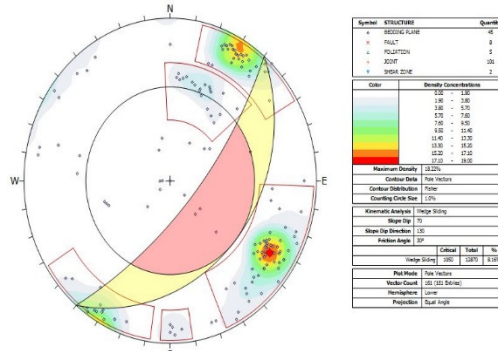

Fig. 5: Wedge Analysis of the Nkran West Wall at 70°

The kinematic analyses results of wedge failure of the Nkran West Wall with a slope angle of 70° and 80° are as shown in Figures 5 and 6 respectively.
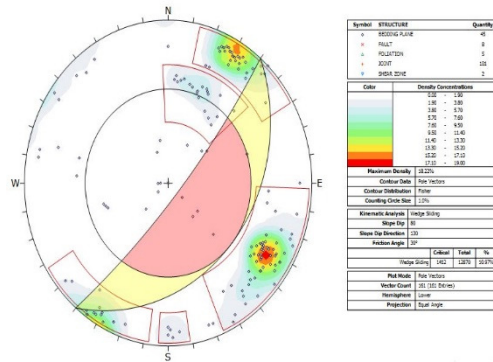

Fig. 6: Wedge Analysis of the Nkran West Wall at 80°

Table 2 shows for the kinematic analysis of wedge failure.

Table 2: Kinematic Analysis of Wedge Failure

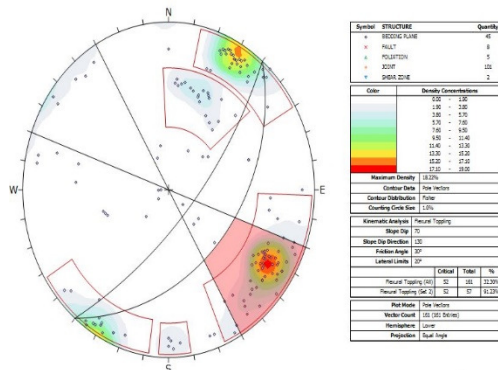| Pit Area	Slope Dip Direction	Slope Angle	Percentage of Total Wedge Failure
Nkran West Wall	130°	70°	8.16%
Nkran West Wall	130°	75°	9.39%
Nkran West Wall	130°	80°	10.97%

Fig.7: Flexural Toppling Analysis of the Nkran West Wall at 70°

Toppling Failure Analysis: A toppling failure occurs when a steeply dipping discontinuity dips away from the slope face and dips into it at an angle greater than the angle of friction of the slope (Hoek and Bray, 1981). In analysing toppling, a slip limit based on joint frictional cone and pit slope, which defines the area of restriction or toppling, was plotted. The poles that fall within the region created by the slip limit and the toppling envelope forms the region for toppling failure. In this work, the types of toppling failure that were analysed comprised flexural and direct toppling failures. The result of flexural toppling failure for slope angle 70°and 80° are as shown in Figures 7 and 8 respectively. The results of direct toppling failure for slope at angles of 70° and 80° are illustrated in Figures 9 and 10 respectively.
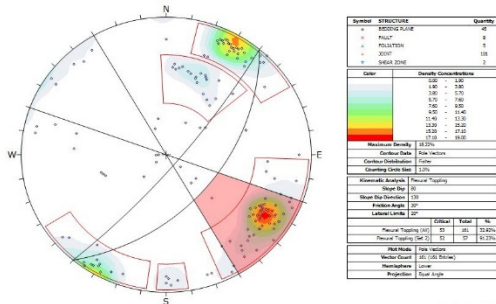

Fig. 8: Flexural Toppling Analysis of the Nkran West Wall at 80°

Table 3 shows for the kinematic analysis of flexural toppling failure.

Table .3: Kinematic Analysis of Flexural Toppling Failure

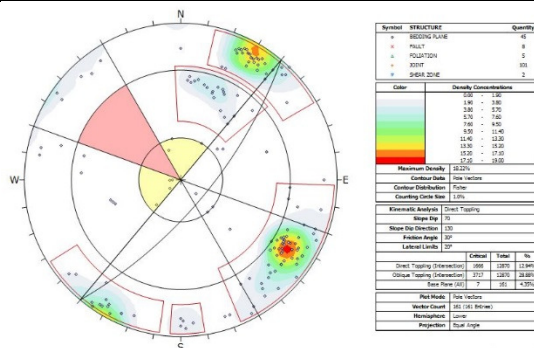| Pit Area	Slope Dip Direction	Slope Angle	Percentage of Total Flexural Toppling Failure
Nkran West Wall	130°	70°	32.30%
Nkran West Wall	130°	75°	32.92%
Nkran West Wall	130°	80°	32.92%

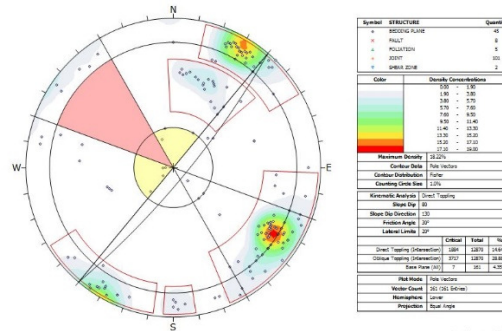**Fig. 9:** Direct Toppling Analysis of the Nkran West Wall at 70°

Fig. 10: Direct Toppling Analysis of the Nkran West Wall at 80°

Table 4 shows for the kinematic analysis of direct toppling failure.

Table 4: Kinematic Analysis for Direct Toppling Failure

Pit Area	Slope Dip Direction	Slope Angle	Percentage of Total Direct Toppling Failure
Nkran West Wall	130°	70°	12.94%
Nkran West Wall	130°	75°	13.54%
Nkran West Wall	130°	80°	14.64%

There is the possibility of all modes failures to occur when the slope angle is increased between 75^0 and 80^0 with flexural toppling dominating. Flattening or reducing slope angle could be done as it reduces the weight of material which in turn improves the stability of the slopes. Controlled blasting should be employed to reduce excessive damage to the walls.

*Conclusion*s: For the kinematic analysis performed using the slope angle per design (70°), the percentage of planar, wedge, flexural toppling and direct toppling recorded were 3.73%, 8.16%, 32.30% and 12.94% respectively. When the slope angle was increased by 5° and 10°, there was percentage increase in planar, wedge, flexural toppling and direct toppling failure of (1.86 and 7.45)%, (1.23 and 2.81)%, (0.62 and 0.62)% and (0.60 and 1.70)% respectively. There is the possibility of all modes to occur when the slope angle is increased with flexural toppling dominating.

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