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# BACK-ANALYSIS STUDY ON SLOPE INSTABILITY IN AN OPEN PIT MINE

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## Abstract

To investigate the sliding from a geotechnical standpoint, as well as the possible causes that influence it. Our analysis follows the chronological order below to investigate the sliding from a geotechnical standpoint and to find the potential causes that influence it. To begin, feedback reconstructs the slide from a geotechnical standpoint; to corroborate the surface collapse, a back-analysis is required. The surface failure will next be checked using the finite difference method and the shear strength reduction by finite difference method (SSR-FD).To determine the impact of geometric parameters on stability, parametric research is conducted. The conceivable cause that has had a direct impact on this slide is demonstrated. This research examines the use of three approaches to do back analysis and determine the layer of slope failure in an open pit mine: limit equilibrium method (LEM), finite element method (FEM), and finite difference method (FDM) are used. The back-analysis of rock mass parameters, as well as the slope failure mechanism and the correctness of this method in the mining engineering area, were performed using LEM, FEM, and FDM. This research has shown that noncompliance with state-of-the-art open pit mining regulations and early planning of the mining procedure can frequently result in critical situations and tragic outcomes.The reverse examination of the slip site allowed us to rebuild the previously observed break and derive the most conclusions possible about the mode, position, and mechanical characteristics that caused it.

**Keywords:** land slide, limit equilibrium method, finite difference method, finite element method, open pit mine, slope stability

## Introduction.

In quarries and open pit mines, slope stability is routinely studied and analyzed. They're found during the planning and slope design stages to assure the mine's long-term stability on the one hand, and to reduce the amount of waste rock extracted on the other.

Slope stability evaluations (mines and quarries) necessitate a thorough knowledge of the site's geology, hydrogeology, seismology, and geotechnics, as well as analytical and numerical methodologies. The degree of site inquiry and the amount of data gathered must be comparable to the complexity of the analysis method employed in order to correctly apply an analysis method. When the slopes show evidence of instability or breaking during manufacture, these evaluations are also performed. It's typical at this point to conduct post-mortem analysis on events that have already transpired. This is known as a slopes instability back-analysis.

Back-analysis is a technique for reconstructing a previously observed failure in order to gain the most information possible on the mode, location, and mechanical characteristics that caused the failure. The shape of the failure surface is a crucial element in determining whether a landslide is natural or manmade. The back-analysis entails sensitivity analysis with 2D slope stability software utilizing the limit equilibrium method. Sensitivity analysis is performed to evaluate which material property has the greatest impact on the slope's stability.

**AnalysisMethods.**Limit Equilibrium Methods are a type of limit equilibrium method. For slope stability studies, limit equilibrium techniques (LEMs) are commonly used. In this study, the Rocscience programme SLIDE 2D limit equilibrium analysis of slope stability is used to do back analysis and determine the material property of the layer that causes the movement.

**NumericalMethods.**The use of numerical methods (NMs) in slope stability research has grown in popularity as a result of significant advancements in computer technology and inexpensive cost. The NMs are an effective tool for resolving a wide range of engineering challenges.Two of these methods are FEM and FDM. This analysis is carried out in our work using the Rocscience Inc. programme Phase2 finite element analysis for excavation and Itasca's FLAC (Fast Lagrangian Analysis of Continua). The safety factors were calculated using the Shear Strength Reduction technique in the FEM and FDM (SSR). The critical slide surface is discovered automatically, and the geometry of the slide surface does not need to be specified in advance, which is one of the key advantages of the SSR technique over LEM slope stability analysis. Slope stability is determined utilizing rock strength features in this SSR technique.

$$C *= \frac{1}{F} * C$$

$$\varphi = \arctan[\frac{1}{f} * tan\varphi]$$

Where C└ and φ└ are rock reduced strength characteristic, (cohesion and friction angle) in proportion to the real values(C, φ).

The back-analysis concept is to assume that the slope in the moment of critical failure has a safety factor of 1.0, and then compute the parameters of the sliding layer in this critical state.

**Methods.** Our study follows the historical order below to investigate the sliding that occurred in the coal open pit mine from a geotechnical standpoint and to find the likely causes that influenced it. To begin, geotechnical feedback reconstructs the slide; a back-analysis is necessary to determine the nature of the slip and the position of the surface collapse. Then, using the finite difference approach and the shear strength reduction by difference finite method (SSR- FD), the surface failure is checked. In addition, a parametric investigation of the influence of geometric parameters (bench height and dip angle) on stability is conducted. Finally, we show the plausible cause that has directly influencedthissliding,namelythemethod ofexploitation.

**Observation of the landslide area and Geotechnical model.** The characteristics of the failure surface can be summarized as follows based on first hand observations made on the landslide, the North-South geological portion of the landslide (Fig. 1, b) and its structure, the documentation supplied, and the study work that has been done:

**1.** The movement has mostly damaged the exploited phosphate layer, which is topped by layers of marly limestone.

2. The presence of a Pelitic and clay formation of the lower Thanetian at the base of the phosphate layer suggests a weak resistance compared to the phosphate layer.

The sliding surface is positioned at the level of the marl layer, and its shape follows the topography of the marl layer, as seen above.

Fig.2representsthelimitequilibriummodelthatintegrates the topographic and geological data used to carry outthe back analysis of sliding of the north flank of the Mine.

The main geotechnical parameters of the rocks for the fourlayers constituting the geological formation of the depositarepresentedinTable1.

**Reflection on the possible causes of the sliding.** In order to fully comprehend and understand the sliding process, various contributing aspects must be considered, including hydrological and hydrogeological conditions, geometric parameters (slope height and dip angle), and dynamic effects (blasting effects).

In the examination of stability, hydrological and hydrogeological parameters play a significant role. As a result, the effect of these characteristics had no direct relationship to the movement's initiation.

Vibrations in the mine can arise from two different places. Vibrations induced by earth- quakes are the first, while those caused by blasting are the second. In stability assessments, these vibrations are a significant destabilizing factor to consider.

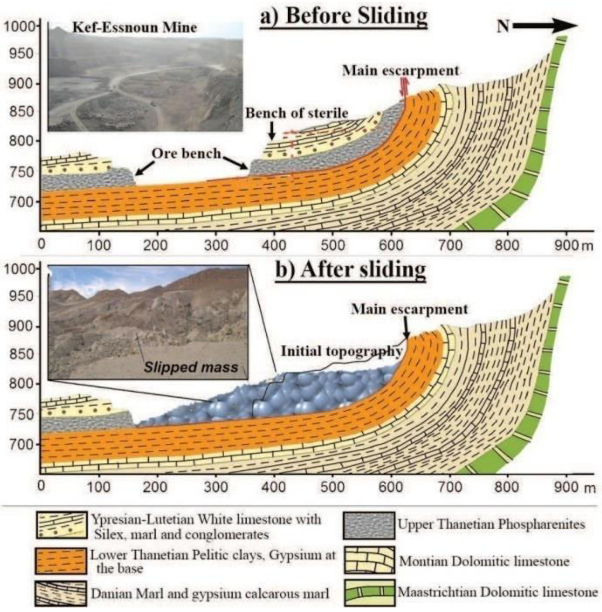

Fig.1.Geological section of the mine: a–before sliding; b–after sliding

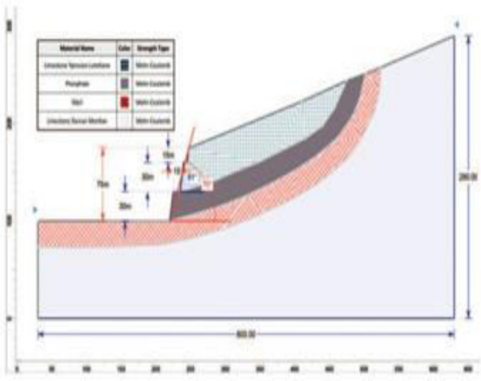

Fig.2.Limitequilibriummodelusedinthebackanalysis

Vibrations caused by an earthquake are rare, but can affectthe entire slope at the same time.

The mine makes extensive use of explosive blasting. On the rock massifs, the vibrations produced by explosive blasting have two fields of action. They impact the integrity of the rocks or their compression resistance parameters on the one hand, and when destabilizing events are performed, they can cause the slope to slide. The shock wave propagates through the rock mass, causing these vibrations. In this circumstance, firing production bullets repeatedly can add to the mine's instability deterioration.

Parametric research will be conducted to determine the impact of geometric parameters and felling work on the sliding of our site.

Table1Geotechnicalparametersofsoils

| Materials | UCS | γd | E | C | φ | ψ |
|---|---|---|---|---|---|---|
| | (MPa) | (kN/m$^3$) | (kPa) | (kPa) | (°) | (°) |
| 1 | 58.84 | 27 | 27000 | 5400 | 37 | 7 |
| 2 | 49 | 21 | 24000 | 2300 | 35 | 5 |
| 3 | 9.58 | 23 | 1000 | C□ | □<br>□ | 0 |
| 4 | 19.17 | 27 | 27000 | 3600 | 37 | 7 |

C└and□└:Unknown values(to be determined).

UCS: Unit compressive strength, γd: dry unit weight,□:Poisson's ratio, E: Young's modulus, C: cohesion, φ: Internal friction angle, ψ:dilatancy

**Results and Discussions. LEM Back Analysis**. Back- examination of the rock mass properties and investigation of the slope collapse process were performed using the LEM and FDM methods in this work. First, the shear strength values of the marl layer were recalculated using a 2D slope stability limit equilibrium analysis and sensitivity analysis. The slope failure process was then numerically examined using FDM modelling, using the back analyzed characteristics of the marl layer.

**Sensitivityanalysis**.Because all other factors of the slope are known, sensitivity analysis allows researchers to assess the influence of a single unknown variable. One input parameter varies in this study, while the other input parameters remain constant. A sensitivity analysis identifies which input parameters are critical for determining slope stability and which have a smaller impact on instability. The cohesiveness and friction angle of the Marl layer were investigated during the sensitivity analysis. The results are shown in Fig. 3 as sensitivity graphs.

According to the graphs (Fig. 3) depicting the fluctuation of the SF as a function of the cohesion and internal friction angle of the marl layer, the values of cohesion (C) and angle of friction () for a safety factor of 1 were 120 kPa and 16.47°, respectively.

**FDM Analysis.** The SSRFD approach was utilized to better understand the geometry and location of the surface failure in this portion. FLAC2D software was used to model the slope, which provides a two-dimensional explicit solution that allows for massive deformations and instabilities to be simulated. The model was assigned the geotechnical parameters of the marl layer, namely cohesiveness and friction angle, which were acquired from the LEM back analysis, as well as the other geomechanical characteristics of the north flank of mine employed in the SSR-FD modelling. The safety factor was calculated to be 0.87 (SF 0.87).

The surface failure is also located along with the marl layer, as shown in Fig. 4, allowing us to derive the following conclusion: SSR-FD confirms slope instability, with the layer of marl as the sole feasible sliding surface.

**LEM Parametric Study.**The goal of this section is to establish that the conditions of stability would have existed during excavation work at the location where the landslide developed if the height and angle of the embankment had been reduced previously. For varied angles and bench heights, LEM analyses are performed in order to compute the safety factor (SF) using three approaches (Bishop simplified, Spencer, and GLE/ M-Price's) along their critical failure surface. These analyses will be carried out in three different scenarios. The first scenario entails lowering the angle of inclination to 75 degrees (75°) in order to achieve a 63-degree edge angle without changing the bench height (H 30 m).The second option is to lower the bench height to 15 metres (H 15 m) with an 80-degree tilt angle (80°). Finally, we reduce the slope angle to 75 degrees (75°), but keep the bench height at 15 metres (H 15 m). All of these studies are carried out in both static and dynamic loads. Seismographs are commonly used to measure speed and seismic waves on the ground. The horizontal and vertical accelerations in our example are 0.05 and 0.0125 m/s2, respectively. Table 2 summarizes the outcomes of the calculations.

After analyzing the data (Table 2) (Fig. 5), we can see that all of the safety factors calculated by the various approaches are greater than the minimum threshold for slope stability (SF 1), allowing us to draw certain conclusions.

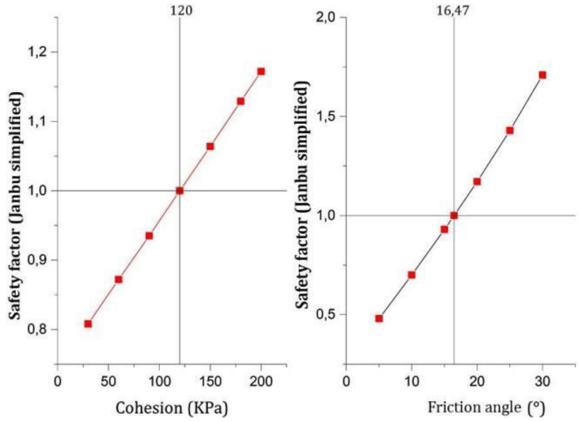

Fig.3.Cohesion and friction angle for SF 1

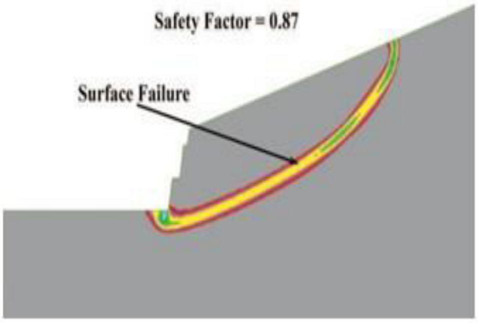

Fig.4.Surface failure and SF value from FLAC

In the first case, all of the safety factors calculated by the various methods in both cases (static and dynamic loads) are less than the accepted minimum threshold for slope stability (SF 1), implying that the flank North is unstable, according to the Bishop simplified method (SFstatic 0.938 and SFdynamic 0.825).

In the other cases, all of the safety factors are in critical condition (SF 1) for the first approach, which excludes the seismicity coefficient (static load), confirming the influence of the angle and bench height on the mine's flank stability with a minimum safety factor given by the Bishop simplified method SF 1.063 and SF 1.073.

Under dynamic load situations, all of the security factors calculated by the various approaches are less than or equal to 1 (SF 1), with the Bishop simplified method SF 0.932 and SF 0.940 providing the lowest security factor.

In light of these findings, it may be inferred that the parameters investigated had no direct impact on the 2007 slip. As a result, we have doubts regarding the way of operation we chose: bottom to top. Our research will revolve around recreating a sinking operation (from top to bottom) and examining the state of the slope under the same conditions that caused the slip.

Table2Summary of Safety Factors (SF) Calculation Results

| Parameters | Cases | Methods | | |
|---|---|---|---|---|
| | | Bishopsimplified | Spencer | GLE/ Morgenstern-Price |
| H=30m, α=75° | Staticload | 0.938 | 0.984 | 0.962 |
| | Dynamicload | 0.825 | 0.886 | 0.852 |
| H=15 m, α=80° | Staticload | 1.063 | 1.124 | 1.100 |
| | Dynamicload | 0.932 | 0.996 | 0.970 |
| H=15 m, α=75° | Staticload | 1.074 | 1.135 | 1.112 |
| | Dynamicload | 0.940 | 1.006 | 0.980 |

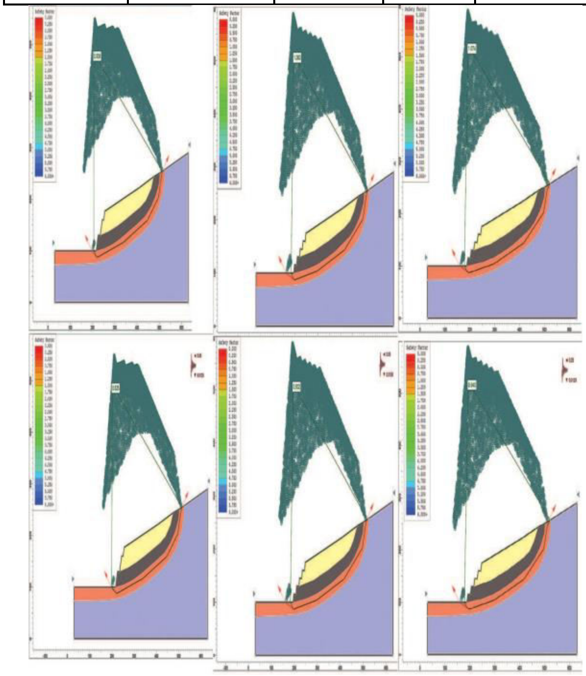

Fig.5.Safety Factors under static and dynamic load from SLIDE

Simulationoftheoperatingmethod.In this section, we'll simulate the exploitation method while looking at the impact of the exploitation (digging cutting trenches) on the mine's north flank stability. The calculations were carried out in phases (excavation sequence), with the phase prior to operation taken into account. The various sequences are depicted in Fig. 6.

**Work Phasing.** We'll work our way through a computation in stages (Fig. 7). Before any excavation is done, the initial phase is investigating the stability of the mine's north flank. The second phase entails the mine's opening and the start of the exploitation process. The following stages are the excavation phases, which are scheduled at regular intervals according to the long-term plan, up to the last phase, which marks the end-of-life flank.

The stability analysis will be carried out with the use of Rocscience Inc.'s Phase2 finite element analysis for excavations programme. Static and dynamic loads will be used in the computations.

Analysis of stability under static load. Table 3 summarizes the calculations, and Fig. 7 depicts the maximum shear stresses and safety factors (in static state) for various excavation phases.

According to the numerical modelling results obtained using the shear strength reduction by finite element method (SSR-FE) under static load (Fig. 7) (Table 3), we find that: before exploitation (Phase 1) (Fig. 7), the safety factor provided by SSR-FE is greater than the minimum admitted threshold for slope stability (SF 4.35), implying that the natural slope is stable in the long run.

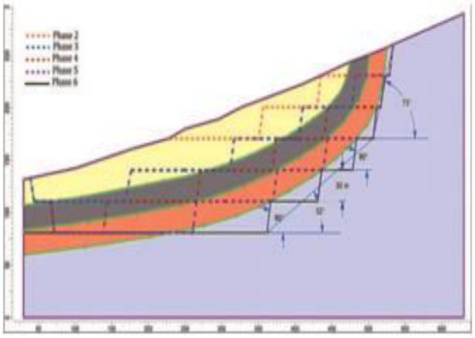

Fig.6.Excavation sequence

All of the safety factors provided by different excavation phases after excavation (Fig. 7) are larger than the permissible slope stability criterion (SF 1.3). It means that the mine's north flank is stable, notwithstanding the excavation work that has been done.

Under dynamic load, stability analysis is performed. The goal of this study is to confirm the mine's northern flank's stability under dynamic solicitation. The basic idea behind this calculation is to impart a constant acceleration to the rock mass that is equal to the greatest acceleration experienced during blasting. Table 4 summarizes the calculation findings (Fig. 8) acquired.

The findings of the numerical modelling of safety factors under dynamic load (Table 4) for different excavation phases show that the values are above the approved minimum slope stability threshold (SF 1.1) (Fig. 8), implying that the mine's north flank will stay stable in the long run.

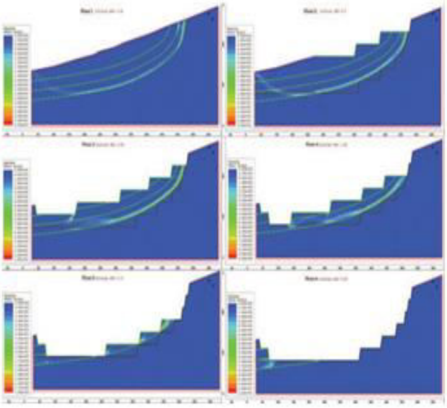

Fig.7.Maximum shear stress and safety factor under static load

Table3 Safety factors for different phases under static conditions

| Excavationphases | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 |
|---|---|---|---|---|---|---|
| Safetyfactors | 4.35 | 5.70 | 2.52 | 1.53 | 1.37 | 4.10 |

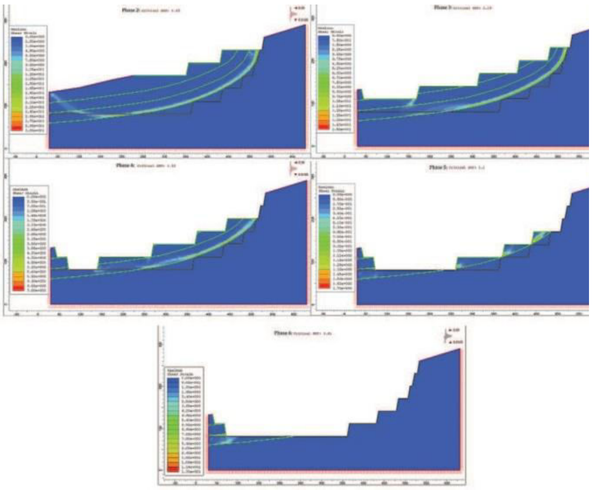

Fig.8.Maximum shear stress and safety factor under dynamic load

Table4Safety factors for different phases under dynamic load condition

| Excavationphases | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 |
|---|---|---|---|---|---|---|
| Safetyfactors | — | 4.63 | 2.19 | 1.32 | 1.1 | 3.81 |

**Conclusions.** The reverse examination of the slip site allowed us to rebuild the previously observed break and derive the most conclusions possible about the mode, position, and mechanical characteristics that caused it. These values were calculated for a critical state (SF 1), with cohesion (C) of 120 kPa and internal friction angle (φ) of 16.47 °.

The rupture occurred in the marl layer, according to the stability analysis carried out on the mine's northern flank using a rigorous numerical methodology (finite difference method), which confirmed the field findings. The parametric study revealed that the mine's flank remains unstable even when the height and angle of dip are reduced sufficiently, with the safety factors under static and dynamic loads estimated by the simplified Janbu method at 1.074 and 0.940, respectively, for steps of 15 m in height and 75° in dip.Non-compliance with state-of-the-art, open pit mining standards and early planning of the mining process can most often lead to critical conditions and disastrous effects, according to the slip analysis performed on the mine's north flank.

The top-down sinking of the mine's north flank has increased the stability of the entire slope during the exploitation phase.

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