Slope Stability Study in Quarries by Different Approaches: Case Chouf Amar Quarry, Algeria

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Abstract. The Lafarge -M'sila group's cement plant (Algeria) is supplied by the Chouf Amar limestone quarry, which allows great quarrying at the national level with annual productions of 4.2 mt / year, since several sliding in previous years have disrupted the exploitation and production of the quarry, and in the strategy of the Lafarge group increased its production up to 5mt / year in the medium term 2020-2030; a stability study is necessary to ensure production under the right conditions, the aim of our work is to study Chouf Amar stability and identify the important causes of the landslides that have influenced the site in question. We start with an empirical approach through a geomechanical characterization of the massif was put in place to highlight the instability at the level of the various rock formations. then, a stability analysis was carried out using two different approaches: the analytical approach using the limit equilibrium method (Slide 6) and the numerical approach using two methods: the finite element method (Phase 2) and the finite difference method (Flac) in the static and dynamic case considering the state of dry and wet marls. The results show an optimal state of stability on the scale of the full profile north flank of the quarry and bad stability on the scale of the bench's of the different levels and the main facies of the potential slide is that of the marls.

1. Introduction
The stability of the slopes of surface mines during their exploitation is an equation with several variables (the geological conditions, the mechanical parameters and the characteristics of the networks of discontinuities), this problem imposes the continuous control of the geometrical, technological and safety parameters, the phenomenon of landslides in surface mining operations is quite frequent [1]. A landslide, if it were to occur, would cause significant damage and halt production.

Before starting a stability analysis, it is important to collect the relevant information for this analysis, in sufficient quantity and precision to correctly use the chosen technique. Depending on the type of structure, the properties that most control the stability of the excavation vary. In the case of an open pit, these properties are the orientation, the dip, the spacing and the continuity of the discontinuities present in the rock mass [2]

Several approaches, separated into three main categories, exist in order to analyse the stability of open slopes. Several of them make it possible to take into account many factors such as water,
earthquakes or the addition of support elements. These main categories are empirical, analytical and numerical approaches. [3]

In order to take into account, the effect of discontinuities in the behavior of rock massifs and the stability of rocky slopes. Classification systems geomechanics, limit equilibrium calculations and kinematic analysis, there are also numerical methods. Are the main methods used in the geo-mining literature, each method has advantages and disadvantages [4].

2. Materials and methods
The study of the stability of a mine (or quarry) makes it possible to analyse the state of stability in order to ensure a secure environment for workers and optimal exploitation. The control and monitoring allow to follow the progress of the works and to ensure their progress in the best conditions previously established.

Analysis of the stability of open slopes requires an understanding of the site's geology, hydrogeology, seismology and geotechnics in addition to knowledge of analytical and numerical methods [5]. Today, many software programs for analysing the stability of slopes are based on calculation methods and hypotheses and provide different information, depending on the basis of their calculation, which makes their use much faster and more accessible.

The objective of this paper is to study the stability of the limestone Chouf Amar quarry on the one hand, and on the other hand, since several landslides occurred during the previous years (figure 1) [6] disrupted the operation we will analyse the shifts from a geotechnical point of view and to identify the important causes that influenced them. Our study will follow the following chronological order:

![Figure 1. Photos representing landslides in the Chouf Amar quarry](image1.png)

First, fieldwork will allow data acquisition, along the cutting edge of Lafarge quarry 'in the different levels (figure 2). The structure of the quarry massif is approached in order to determine the orientations of the different families of discontinuities and their spacing.

![Figure 2. Location map of Lafarge quarry- Chouf Amar -M'sila (Algeria)](image2.png)
Next, an empirical (or geomechanical) classification of our site, by the application of the various systems, namely RQD (Rock Quality Design), RMR (Rock Mass Rating), and SMR (Slope Mass Rating) of the different layers that constitute it, which allowed us to have an understanding of the quality of the rock massifs in order to verify the stability by stereographic projection.

Finally, a stability analysis will be performed by two different approaches: Analytical approach by the limit equilibrium method (Slide 6), in this method the Morgenstern-Price method was chosen to calculate the safety factor for the slice. It is one of the most precise methods currently available and also has the advantage of properly analysing circular and non-circular surfaces [7], and numerical approach using two methods: the finite element method (Phase 2) and the difference method finished (Flac) in order to validate the results found by the previous approaches. In this study a minimum safety factor of 1.3 is required for static analysis and a safety factor greater than 1.10 for dynamic analysis [8].

2.1. Reflection on the possible causes of the slide in Chouf Amar quarry

No event (earthquake, frost period or heavy rain) has been directly associated with quarrying phenomena. In this situation, it is difficult to find a simple and satisfactory explanation for the causes of the instability. For this reason and to understand and analyse the sliding mechanism, two influencing factors must be taken into account, such as the hydrogeological conditions and the dynamic effects (blasting effects).

Hydrogeological parameters play a major role in the analysis of stability. In our case, the presence of marl benches interspersed among the limestones with the infiltration of precipitation water can create cases of instability. In Lafarge quarry, vibrations can come from two main sources. The first being the vibrations caused by earthquakes and the second being those caused by blasting. These vibrations are an important destabilizing element to take into account in stability analyses.

In In Lafarge quarry, blasting is widely used. The vibrations created by the blasting of explosives have two fields of action on the rock massifs. On the one hand, they affect the integrity of the rocks or their parameters of resistance to compression and, on the other hand, can cause a collapse of the wall or the slope when destabilizing actions are introduced. These vibrations are the result of the propagation of the shock wave in the rock mass. In this context, production shots fired repeatedly can help worsen quarry stability.

2.2. Collection and processing of structural quarry data and study methodology

The methodology adopted in our research is a combination of different distinct approaches; to quantitatively and qualitatively assess the stability of the quarry-studied. The first stage is devoted to fieldwork. It allows data acquisition, along the quarry face. The structure of the Lafarge quarry massif is approached so as to determine on the one hand the orientations of the different families of discontinuities and on the other hand their spacing. Discontinuities have been measured systematically from several lines located on each tier are flush with the surface of the cutting face of the different levels (figure 3). For geological parameters (roughness and alteration), they are estimated by comparing the appearance of the discontinuity surface with standard profiles published by [9]. The distinction of natural discontinuities of artificial discontinuities created by drilling, shooting or excavation activities is one of the most difficult steps in carrying out this study.

The various rock formations encountered across the quarry face are three layers of limestone: Limestone L1, Limestone L2, Limestone L3 and intercalation of low thickness of marl layer of 3m. After, we merged data from different cracking surveys for each of the two limestone and marl facies. The data are then fed into a software based on stereographic projection to synthesize and represent discontinuity orientations at the study site. This allowed us to get a general idea about fracking in our study site. This task is done using the DIPS V6 software.
Figure 3 - Data collection for RQD calculation

In order to validate the results, found in the previous geomechanical classification approach, the application of the limit equilibrium method by SLIDE and two numerical methods (the finite element method (Phase 2) and the finite difference method (Flac)) in the static and dynamic case considering the state of dry and wet layer of marls are used for good understanding of the fracture mechanism.

3. Results and discussions
In this section, we collected representative samples of our field of study on the different rock formations encountered in the bleachers that outcrop on the land surface and are being mined. The results obtained in this study show that fracturing systems have a strong influence on rock slope stability. The various rock formations of the Chouf Amar quarry present the concentration of poles that correspond to the discontinuity families summarised in the table 1.

Table 1. Orientation of the most important discontinuity families in the career.

|          | Limestone L1 |          | Limestone L2 |          | Limestone L3 |
|----------|--------------|----------|--------------|----------|--------------|
|          | Dip (°)      | Dip Direction (°) | Dip (°)      | Dip Direction (°) | Dip (°)      | Dip Direction (°) |
| Set 1    | 73           | 266      | 74           | 202      | 23           | 59              |
| Set 2    | 34           | 327      | 80           | 255      | 14           | 334             |
| Set 3    | 26           | 205      | 77           | 145      | 16           | 290             |
| Set 4    | -            | -        | 71           | 113      | -            | -               |

The data are then introduced into software based on stereographic projection allowing to synthesize and represent orientations of discontinuities on the study site 'figure 4'

3.1. Empirical approach
3.1.1. RQD (Rock Quality Design) classification of the rock mass of the quarry. In Chouf Amar's quarry drill core no longer exist. In this case, when the drill core are not available but the discontinuities are visible on the display surface (the free face of the bleacher), the RQD can be estimated from the number of discontinuities by linear survey [10]. The RQD is written as follows:

\[ RQD = 100 e^{-0.1\lambda} (0.1 \lambda+1) \]  

(1)

Or: \( \lambda \): linear frequency of discontinuity, \( \lambda = N / L \) (Crack / meter),
Figure 4. Stereographic projection of discontinuities of layers L1, L2 and L3
The RQD results of different rock formations are summarized in the table 2

**Table 2. RQD results for different layers in Chouf Amar quarry**

| Layers         | Average frequency | Average spacing | RQD  | Quality |
|----------------|-------------------|-----------------|------|---------|
| Limestone L1   | 10,2              | 0,09            | 72,84| Fair    |
| Limestone L2   | 18                | 0,05            | 46,28| Poor    |
| Limestone L3   | 14,3              | 0,06            | 58,15| Fair    |
| Marl           | 19,54             | 0,05            | 41,85| Poor    |

According to the analysis of the RQD parameters, we see that the massif is formed mainly by three layers of limestone and a marly intercalation whose quality varies from poor to average.

### 3.1.2 RMR and SMR

This approach is based on the stability assessment index called SMR obtained from the RMR classification by adding a factor adjustment factor and another correction factor in depending on the excavation method. The table 3 presents the different results obtained.

**Table 3. RMR, SMR classification of rock formations**

|                     | Limestone L1 | Limestone L2 | Limestone L3 | Marl |
|---------------------|--------------|--------------|--------------|------|
| Uniaxial compressive Strength (Rc) | 7            | 4            | 4            | 2    |
| Rock Quality Designation (RQD) | 13           | 8            | 13           | 8    |
| Spacing of discontinuities | 20           | 20           | 20           | 10   |
| Condition of discontinuities | 10           | 0            | 10           | 0    |
| Groundwater conditions | 15           | 15           | 15           | 15   |
| RMR                 | 65           | 47           | 62           | 35   |
| SMR                 | 69           | 41           | 68           | 21   |
| Description         | Good         | Fair         | Good         | Bad  |
| stability           | Stable       | Partially Stable| Stable      | Unstable |

The results of the SMR classification show that the quarry presents possibilities of ruptures of different types (planar, dihedral, tilting) at the level of the limestone rock formations L2 and the marl layer, the other layers L1 and L3 considered to be stable rocks. In general, the empirical SMR method remains a rapid analysis tool which can give a general idea on the slopes of stable slopes based on qualitative parameters. However, this method cannot guarantee reliable results. It is necessary to analyze each type of rupture (planar, Wedge, Toppling ...) using tools which take into account all the parameters which influence stability, in particular the safety factor. From the results of this approach, we can conclude that the career presents a risk of instability with modes of ruptures in corner and in plan, in particular at the level of marly intercalations.

### 3.2. Analytical approach

#### 3.2.1. Stability analysis by kinematic analysis by stereographic projection

The identification of the failure modes for the different families of identified discontinuities, associated with the different lithological domains is carried out by a kinematic analysis using stereographic projection (DIPS V6). The latter makes it possible to better visualize the data in a fairly comprehensive manner, which provides us with the opportunity to delimit 03 critical zones concerning planar failure (figure.5), wedge (figure 6), and toppling (figure 7). The results are illustrated in table 4.
Table 4. Kinematic analysis results

|                | Planar | Wedge         | toppling |
|----------------|--------|---------------|----------|
| Limestone L1   | -      | F2            | -        |
| Limestone L2   | F4     | F2 & F3, F3&F4, F3&F2 | -        |
| Limestone L3   | -      | -             | -        |

We note that, a possibility of planar failure in layer L2 (F4) and different wedge failure in the same layer and only possibility in layer L1 (wedge failure of F2).

Figure 5. Planar failure by kinematic analysis for layers L1, L2 and L3

Figure 6. Wedge failure by kinematic analysis for layers L1, L2 and L3

Figure 7. Wedge failure by kinematic analysis for layers L1, L2 and L3
3.2.2. Stability analysis by the limit equilibrium method (Slide 6). In order to validate the results found in the previous approaches, the application of the limit equilibrium method has proven to be a means which makes it possible to achieve the objective. In this section, it is necessary to present the numerical model which integrates the topographic and geological data to carry out this study (figure 8).

![Figure 8](image)

**Figure 8.** Full profile of the north side of the quarry Chouf Amar (M'sila),

The quarry stability study is carried out in two stages, firstly, stability study on the scale of the full profile north and then on the scale of the benches which are analyzed (figure 9). In both cases, the study is initiated by simple calculations used to identify the most likely failure modes in the static and dynamic case taking into account counts the state of marl (dry and wet).

![Figure 9](image)

**Figure 9.** Diagram represents the different profiles.

The results of calculation of the safety factors by SLIDE using method of Morgenstern-Price for 4500 sliding surfaces (circular and non-circular) in the static and dynamic case are illustrated in figure 10, with the main failure surfaces associated with these values of safety factor of the full profile.

According to the results obtained from the safety factor for the 4 profiles it is found that the quarry is stable and the profiles of various rock formations L1, L2 and L3 are also stable in the static and dynamic state in both dry and wet marl cases regardless of the circular surface and non-circular with Safety factor between SF= 1, 53 and SF= 2, 09.
We note the method of limit equilibrium by slices, used by the Slide software, sometimes has difficulty targeting areas of low thickness and strength like the marl layer to calculate the most critical surfaces. To eliminate all doubts concerning the identification of the most critical surface, the use of numerical modeling software capable of properly studying all the elements present in the massif is indicated.

3.3. Numerical approach
3.3.1 Stability analysis by the finite element method (Phase2)
With recent developments in hardware and software, a properly conducted finite element analysis can be performed quickly and at relatively low cost [11]. In the numerical modeling and the stability study of the career of Chouf Amar, the analysis will be done from the finite element method using the software of finite element numerical modeling Phase2. The stability analysis will be done in two cases (Static and dynamic) we take into consideration the influence of water on the mechanical parameters of the Marl layer (Dry and wet).

In the first static approach: - In the first case (dry marl), all the safety factors given by the finite element method for the 4 profiles are greater than the minimum acceptable threshold for slope stability (Sf > 1.3), which implies that the 4 profiles are stable in the long term.
- In the second case (wet marl), the safety factor results given for the two profiles L2 and L3 are in critical condition, which implies that the wet marl had a significant influence on the stability of the rocks at the scale of the banks. The safety factor given for profiles L2 and L3 are 1.3 and 1.23 respectively.

In the second approach where we took into account the blasting effect, we note that: in the case where the marl is dry, all the safety factors given are greater than the minimum accepted threshold for slope stability (Sf > 1.1), which implies that the 4 profiles are stable in the long term. However, in the case of wet marl (figure 11), we note that the profiles L2 and L3 are unstable, which implies that the blasting effect had a significant influence on the stability. (Sf = 1.03 and Sf = 1.09 for profiles L2 and L3 respectively).

For confirmation of these calculation results of safety factor other well specified numerical method is used.
3.3.2 Stability analysis by the finite difference method (Flac). In this method the safety factor is calculated by the technique of SSR-DF (Shear Strength Reduction - Finite Difference Shear Resistance). The influence of the sliding surface can be taken care of by the SSR-DF technique because during the calculation phase only one surface can be considered as resulting from the reduction of the plastic parameters cohesion (C) and internal friction angle (φ) of rocks [12]. The results of the analysis performed by the finite difference method by FLAC software are shown in (figure 12).

![Figure 11. Total displacements observed during the dynamic analysis of the profiles (wet marl)](image)

![Figure 12. Safety factor for different profiles by the finite difference method](image)

The shear strain and safety factor (in static and dynamic conditions) for different profiles by MDF using FLC are represented in (figure 13).

From the results obtained from safety factors for different profiles by the finite difference method (SSR-DF) through the Flac software, we note that:

In the first static state, in the cases (dry and wet marl), all the safety factors calculated by the finite difference method for the 4 profiles are greater than the minimum allowed threshold. But in second dynamic state, in the case where the marl is dry, all the safety factors given are greater than or equal to
the minimum accepted threshold for slope stability ($S_f \geq 1.1$), which implies that the 4 profiles are stable in the long term and the quarry can be operated under safety conditions. But, in the case of wet marl, (figure 13) we note that the profiles L2 and L3 are unstable, which implies that the effect of explosive blasting work had a major influence on stability. ($S_f = 1.01$ and $S_f = 0.99$ for profiles L2 and L3 respectively). The other two profiles: L1 and full profile are stable with safety factor 1, 1.14 and 1, 1.12 respectively.

Figure 13. Safety factors and critical surfaces obtained by the finite difference method (dynamic state-wet marls)

4. Conclusions
In this paper, the study of the stability of Chouf Amar’s quarry was made by different empirical, analytical and numerical approaches.

The characterization allowed us to make the following observations:
- The values of RQD vary between 41% and 72%, considering that the quality is poor for marls and limestones L2, average for limestones L1 and L3.
- The Rock Mass Rating (RMR) classifies the massif as being that formed of rock of poor quality for marl, medium for L2 limestones and good quality for L1 and L3 limestones.

The method of SMR (Slope Mass Rating) confirmed the findings of other classifications concerning the quality of the massif and the existence of instability at the facies.

The kinematic analysis of the different facies shows that the quarry presents risks of sliding of different types, depending on the planar failure and the wedge failure.

The results of analysis by the limit equilibrium method through the Slide software clearly show that the quarry is stable in different cases of evaluation (static / dynamic, Dry/ wet). On the other hand, the results of the numerical modeling by Phase2 and Flac also confirm that the quarry presents a poor stability, particularly at the level of the steps with marly intercalation which influences the value of the safety factor estimated in the various previous evaluation cases. Therefore, we conclude that the limit equilibrium method does not support thin layers to calculate the most critical surfaces.

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