Study Effect of Geological Parameters of the Slope Stability
by Numerical Modelling, Case Limestone Career of Lafarge-
msila, Algeria

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Abstract. The stability of slopes in open pit mines is an issue of great concern because of the significant detrimental consequences instabilities can have. The stability of open pit is controlled by several geotechnical and geological factors, the most important cracks in the rocks as well as various and homogeneous of layers. In the case of study presence of a tensile crack is the most critical case in the calculation of factor of safety because of the possibility of the presence of waters in this crack that influence negatively on the stability of the open pit with traction crack. Then the mechanical characteristics of the crack filling material are more degraded than those of the marl layer between the layer of limestone open pit LAFARGE.

With the differences both methods possess, sensitivity analyses and comparisons of result were done using Slide, Flac and Plaxis software for the analysis of sliding and stability of open pit. These evaluations have been performed by the limit equilibrium method through the SLIDE software, the finite element, finite difference methods through PLAXIS and FLAC respectively.

1. Introduction

In mining engineering field, stability analyses aim to support the safe and functional design of rock and soil slopes. Firstly, analyses can be carried out in order to determine the critical parameter of work stability. Parametric analyses allow one to assess physical and geometrical problem parameter influence on the slope stability Coates [1]. A rock and soil slope stability analysis allow one to evaluate: The optimal staged excavation or construction time sequence determination; the role, which design parameters such as slope angle and excavation or embankment height, play in the work stability; Consolidation work such as retaining walls, drainage system or rock bolting, which can stabilize Slope. Corbyn [2].

The slope stability analyses in open pit mine or quarry using the geological, structural, material property and hydrogeological information that has been brought together in the geotechnical model. The fundamental objective of the slope design process is to enable a safe and economic design for the pit walls at the bench, inter-ramp and overall slope scales.

The majority of rock slope instability is caused by individual discontinuities. This is because the strength of the intact rock can be high, with the result that the pre-existing discontinuities are the weakest link. Saadoun et al [3].
The stability of a rock slope is highly dependent on the configuration and spatial distribution of its discontinuities and the maximum height of the slope (Read and Stacey, 2009) [4]. The stability of small slopes is controlled by discontinuities, and the most common failure modes are planar, in wedge, and toppling, which can be evaluated using limit equilibrium methods. However, when the height of a slope becomes much larger than the persistence of its discontinuities, ruptures also involve intact rock in failure mechanisms that are generally little understood (Hustrulid et al., 2000) [5]. The relative motion on the discontinuities leads to their propagation through the intact rocks, creating new fractures in the rock matrix.

Of the different failure mechanisms described by Sjöberg (1996) [6], the step-path type is probably the most important for evaluation in high slopes. In this mechanism, the overall rupture surface is formed by the union of several pre-existing discontinuities that propagate by a process called coalescence. These processes are also observed on the microscale. It noted that crack propagation under compressive conditions is caused by tensile stresses that act near the tips of pre-existing cracks. Under these conditions, propagation is initiated, forming primary tensile cracks that propagate in the direction of the applied load (wing cracks Einstein and Dershowitz (1990) [7], amongst others).

2. Factors influencing slope stability

The analysis of deformation processes in open-cast mines must take into account the common influence of many factors and the important can be subdivided in:

2.1. Geological Structure

The main geological structure which affect the stability of the slopes in the open pit mines are:

- Amount and direction of dip
- Intra-formational shear zones
- Joints and discontinuities
- Faults

Instability of rock slope may occur by failure along pre-existing structural discontinuity, by failure through intact material or by failure along a surface formed partly along discontinuity and partly through intact material.

From a general point of view, rock masses can be considered as both geological objects and mechanical objects. The study of rock mass stability requires knowledge of structural geology and rock mechanics. Geologically, there is a great diversity of rock masses depending on:

- the nature of the rock matrix and its petrographic and mechanical characteristics
- discontinuities at all scales and of all types, affecting the massif
- the variability in the space of the rock matrix / discontinuities.

2.2. Lithology and Ground Water

The rock materials forming a large pit slope determines the rock mass strength modified by discontinuities, folding, faulting, old workings and weathering. Low rock mass strength is characterized by ravelling, circular, and rock fall instability like the formation of slope in Massive sandstone restricts stability. Pit slopes having soil alluvium or weathered rocks at the surface have low shearing strength and the strength gets further reduced if water seepage takes place through them. These types of slopes must be flatter Hoek [8].

Ground water causes increased up thrust and driving water forces and has adverse effect on the stability of the slopes. Chemical and Physical effect of pure water pressure in joints filling material can thus alter the cohesion and friction of the discontinuity surface. Physical effects of providing uplift on the joint surface, reduces the frictional resistances. This will reduce the shearing resistance along the potential failure plane by reducing the effective normal stress acting on it. Physical and the chemical effect of the water pressure in the pores of the rock cause a decrease in the compressive strength particularly where confining stress has been reduced. Hoek [9].
3. Cracking in rocks
Many studies performed by Park and Bobet (2009) [10], on rocks specimens subjected to uniaxial compression, up to three types of fractures propagated as a result of the applied load (Figure 1): primary cracks generated by tension, which initiated at the edges of the crack and contained no pulverized material, and two types of secondary cracks (coplanar and oblique), which are generated by shear and feature pulverized material on the failure surface.

![Figure 1. Propagation of a crack subjected to compression [10].](image1)

Coalescence is as the connection of pre-existing cracks and discontinuities in a rock material via propagation. The connection type depends on the position of the cracks and the type of propagation involved. Several authors have studied this mechanism. For example, Ghazvinian et al. [11]. Analyzed the influence of the distance between two co-planar cracks in the coalescence in the stability of slopes between them using shear test results and numerical simulation using deferent methods see figure 2.

![Figure 2. Cracks in level 1035 after sliding in Chouf Amar Lafarge career](image2)

4. Numerical modelling of slope stability
Numerical modelling is the efficacy method used to examine surface excavations and support systems, the behaviour problems in rock slope in open pit, designing underground excavations in underground mining and tunnelling. Numerical modelling is also used for describing possible failure types. But some degree of calibration is needed for the numerical models. For this calibration, it needs a detailed understanding of deformation mechanisms and behaviour of the slopes.
In open rock quarries, there are some important parameters such as the slope stability conditions, slope susceptibility, to plan optimum slope angles and possible failure mechanism for slope stability analyses. Also, rock mass properties (rock mass characteristics, geometry of slope and shear strength behaviour of the joints) effect the stability of open quarry. When rock masses are not continuous, then their behaviours are controlled by discontinuities such as bedding planes, fractures, faults and schistocyte planes. Generally, discontinuities have a significant effect on the stability of slopes and the properties of discontinuities control the overall rock mass behaviour (Murat Y et al) [12].

Limit equilibrium methods have served geotechnical engineering, and particularly slope stability problems for many decades. Through force and/or moment equilibrium, these methods calculate a safety factor (SF), which is defined, with respect to the shear strength of the soil, as the ratio of the available shear strength to the shear stress at equilibrium. Their basic characteristic is the simplicity and their proven, through decades of use, validity for relatively simple geometries and conditions. However, stability problems in large-scale open pit mines often involve complexities that are not easily addressed by limit equilibrium methods. In this case, using (the more sophisticated and powerful) numerical methods, such as the finite element method (FEM) and the finite difference method (FDM), provides the engineer with the opportunity to conduct more comprehensive and sound slope stability analyses.

The main advantage of numerical methods is that no assumption needs to be made about the shape, direction and location of slip surfaces: failure occurs “naturally” through zones on which soil's shear strength is unable to sustain the applied shear stresses. Additionally, numerical models are able to generate stress-strain distributions (deformational response), which may be of crucial importance for a robust interpretation of slope behaviour, and also to address and analyze precisely complicated geometries, simulate pit excavation stages and their effect on the stress state, address possible groundwater seepage, etc. On the other hand, it is important that engineers understand not only slope stability principles, but also the limitations of the methods, before using sophisticated computer programs (provoked by their recent, extremely high, user-friendliness) and especially before interpreting and apply the results through design. Particularly in the context of large scale mining slopes, obtaining realistic input information and interpreting the results are the most difficult aspects of numerical modelling Deliveris A et all. [13].

5. Location of Chouf Amar limestone career of Lafarge
The Wilaya of M’sila is located in the Central East parties of the Algeria, 250 km southeast of the capital Algiers; it borders with the provinces of Bouira and Bôrdj Bô Arreridj to the north, east Batna, Biskra southeast, Djelfa and Medea west see Figure 3.
The Morphologically limestone deposit of the career Chouf Amar plant is part of a massive array stretched in a longitudinal direction over more than 150 km. Locally, it is in the form of two separate compartments monoclinal, with an average height difference of 250m, stretched in one direction in a dip angle of 10 ° to 15 ° separated by a relatively deep trough and delimit two buttes which constitute the southern limit and the situation of the quarry it represent in the figure (4).

Basically, just above the dolomitic limestones of the Turonian, based essentially marl foundation of a 70m thick about, consists of grey marl with intercalations of grey and nodular limestone marl, often marl grey limestone and lumachelles. This layer of marl of deferent thickness plays the role of soap to slip and fragilise the quarry stability.

After collecting data on the seismicity of the area as well as the parameters physical and mechanical characteristics of the massif, the dip and direction of the existing discontinuities, we studied the influence of different factors on the safety coefficient by three methods.

6. Methodology

The objective of the present work is to investigate the comparative performance to evaluate stability of career Lafarge by three different software, in the context of slope stability of open pit Lafarge. More specifically, the widely used geotechnical software FLAC of Itasca Consulting Group Inc, PLAXIS 2D and Slide is used by applying the shear strength reduction technique SSRT. The values of safety factor obtained for the same case of presence of a tensile crack in layer of dry marl and the second case is presence of a tensile crack in layer of drained marl from the three methods LEM (software Slide), FEM (software Plaxis) and FDM (software Flac) than to discuss the comparative similarities and differences among them.
In this modelling a simple geometrical model used in our study between two levels 1015 and 1035, see figure 5 in this bench of height of 20m there are two layers of fractured marl of thickness and a layer of limestone C1, the figure 6 represent the model study and table 1 represent The properties of the rock block and the properties of marl intercalation by the Mohr-Coulomb model.

![Study level model](image)

**Figure 6. Study level model**

|          | Re MPa | \(\gamma_d^{\text{insat}}\) kn/m³ | \(\gamma_d^{\text{sat}}\) kn/m³ | C kn/m² | \(\Phi\) (°) | \(\psi\) |
|----------|--------|-------------------------------|-------------------------------|---------|---------|--------|
| Limestone| 42     | 26,5                          | 28                            | 3200    | 23      | 6      |
| marl     | 8      | 22                            | 23                            | 150     | 14      | 0      |

**Table 1.** The physical and mechanical properties of the different layers of level 1015-1035.

7. Results and discussions

7.1. The case of presence a tensile crack in layer of dry marl

7.1.1 Modelling by limit equilibrium method using Slide. In this case the slope of career is stable with safety factor of 1.22 as shows in figure 7.

![Modelling of slope in dry tensile crack by slide](image)

**Figure 7. Modelling of slope in dry tensile crack by slide**
7.1.2. *Modelling by finite deference method using Flac.* The modelling by flac shows a stability of slope in career of limestone Lafarge with safety factor equal 1.18 see Figure 8.

![Figure 8. Modelling of slope in dry tensile crack by Flac](image)

7.1.3. *Modelling by finite element method using Plaxis.* The extent of the plastic points in this model is quite close to the area covered by the shear band (shear strain contours). It is noted that the tension cut off points behind the crest of the slope indicate the tensile cracks formed as a forerunner slope failure phenomenon. the figure 9 represent plastic point in this case by Plaxis with safety factor 1.16.

![Figure 9. Plastic point in the case of presence a tensile crack in layer of dry marl by Plaxis](image)

7.2. *The case of presence a tensile crack in layer of drained marl*

7.2.1 *Modelling by limit equilibrium method using Slide.* In this case the effect of water and crack in slope is cleared with reduction of safety factor to 0.91 as is illustrate in figure 10.
7.2.2. Modelling by finite deference method using Flac.

In the presence of water between the cracks reduction of mechanical proprieties of rocks and effect of stability of slopes as shown in figure 11 with safety factor 0.83.

7.2.3. Modelling by finite element method using Plaxis. In wet case, Figure 12 shows the break mode. The calculated safety factor is 0.80 and the direction of the sliding and displacements is the same one as the dip of the marl intercalations one notices that there is great displacement of the front.

Figure 10. Instability of slope in bench level 1035-1015 with modelling by Slide

Figure 11. Deformed mesh and velocity by flac

Figure 12. Sliding of slope in presence a tensile crack in layer of drained marl
8. Conclusions
In this paper the modelling of stability slope in career limestone Lafarge was studied using three different numerical software packages: FLAC (finite difference), Plaxis (finite elements) and Slide (limit equilibrium) through effect of tensile cracks in layer of marl in two cases dry and drained.

In terms of SF, all three software packages ended up with similar values in two cases.

The case of presence of a tensile crack is the most critical case in the calculation of safety factor because of the possibility of the presence of waters in this crack that influence negatively on the stability of the slope with traction crack.

The study came to the following conclusions:

- Bleachers with interlayers of marl as a sliding plane are more stable than those with cracks as a slip plane because of:
  - The mechanical characteristics of the crack filling material are more degraded than those of the marl layer
  - The dip of the cracks is greater than that of the layer of marl
- The existence of water in traction cracks contributes to the decrease of stability bleachers because of the forces exerted by these waters and which acts as driving forces of the sliding.

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