SLOPE STABILITY ASSESSMENT IN THE OPENCAST QUARRY IN HAMMAM DALAA (M'SILA, ALGERIA). (تقييم استقرار المنحدر في المحجر المكشوف بحمام الضلعة المسيلة ، الجزائر) .Évaluation de la stab...

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SLOPE STABILITY ASSESSMENT IN THE OPENCAST QUARRY IN HAMMAM DALAA (M'SILA, ALGERIA)

(Представлено членом редакційної колегії д-ом геол. наук, проф. О. М. Іванік)

The aim of this study is to identify the main factors that affect the site's stability by using the adequate solutions, which help to solve the problems of slope stability at the quarry of Chouf Amar, Hammam Dalaa, Algeria.

A large amount of geological, hydrogeological and mechanical data has been collected from the site. We realized the study of the influence of different factors on the safety coefficient.

Limit equilibrium techniques have been adapted, taking into account the variability of the site data, to analyze the performance of the existing area of production site.

Results solution under different configurations has shown that stability index is highly affected by hydraulic and seismic factors.

Keywords:slope stability, limit equilibrium, safety factor.

Introduction and previous work. Mining, like all other sectors of industry, has to face the challenges of the 21st century. The challenges do not merely include competitiveness efficiency and respect of the environment, but also include security.

That last one is an increasingly important component when all the risks are involved in mining works (*Tincelin et al., 1982; Piguet, 1999; Piguet et al, 2014*).

In the case of quarries, this problem is crucially important to ensure the production continuity, to avoid reserve loss, and the most important, to preserve human life.

For the current work the rupture modes to develop within the context of the Chouf Amar quarry was delimited to establish the best technical solutions for the operation safety while ensuring an efficient economic development. Moreover, each design is unique and should be established in relation to the specific conditions of the site according to (*Flamme, 2010; Priest and Brown,1983; Hantz, 2012*).

In this study, the approach is the Equilibrium method to assess overall pit slope stability in the limestone quarry of Chouf Amar. According to (*Hudson and Harrison,1997; Wyllie and Mah, 2004; Hoek, 2007; Brown, 1983*).

To undertake our study, different classifications criteria and the assessment of Rock-Mass Properties were applied, starting with Mohr-Coulomb using the Hoek and Brown failure criterion, applying corrections by the weakness coefficient, as well as through the tests that have been done in the National Higher School of Mines and Metallurgy laboratory.

The geological and hydrogeological conditions should be taken into account. Thus, the drained and undrained conditions, including water infiltration into the marl layers (a layer of soap) have been evaluated while applying the recommendation of counted Eurocode 7. To complete our analysis, the exploitation of the recording data of the seismic waves caused by the blasting with the explosive has been counted Eurocode 8 (*Kanli et al., 2006*).

Situation and morphology. The study area is approximately 250 km from Algiers, 10 km north-west of the town of M'sila on the southern foothills of the Hodna Mountains. The deposit is located along the Chouf Amar. Morphologically, the site occupies the southern flank of an elongated mountain bar in the SO-NE direction. The area of the site is included in the Atlas Tellian. Geologically, the region consists of sedimentary formations of secondary and tertiary lying in monoclinal form with a general dip to the south.

Study Area and Analysis of the Problem. Slope-stability conditions at Chouf Amar are generally bad. In 2004, the large-scale instabilities were observed in the Chouf Amar quarry (fig. 1) at the levels of 815, 830, 845, and 860 m; the reserve loss was estimated about 6 million tonnes of limestone, 3450520 tonnes in the upper sliding level A and 2581176 tonnes in the lower level B, as shown in (fig. 2).

Laying out the main material. The calculation of the slope stability consists of evaluating the stability; a deterministic limit-equilibrium approach was selected by evaluating moment and force equilibrium within the slope. For this, mechanical properties for intact rock were determined from laboratory tests, and rock-mass classification ratings using the Hoek–Brown approach were used.

The main geological formations, which can be observed in the quarry are:

1. A step when specific geological feature is traversed by a discontinuity (intercalation of a marl layer between the layers of limestone) as (fig. 3) represents.
2. A step limestone without intercalation (not taking into account the marl intercalation because of their low dip).

For the first case "major problem" is: several factors directly influenced the stability in the quarry, we quote them as follows:

• Current case where the marl layer is dry;

• Water infiltration into the marl layers (layer of soap) (see (fig. 4));

• The effect of seismic waves caused by blasting.

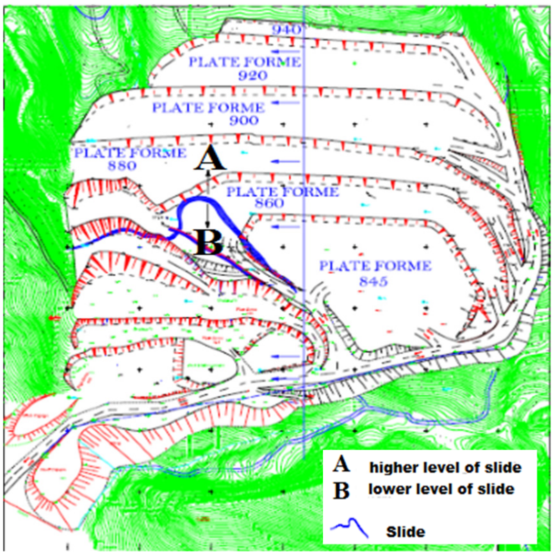

Fig. 1. Slide location (internal report of the company, M'-sila TMN° 2006PXC (2015))

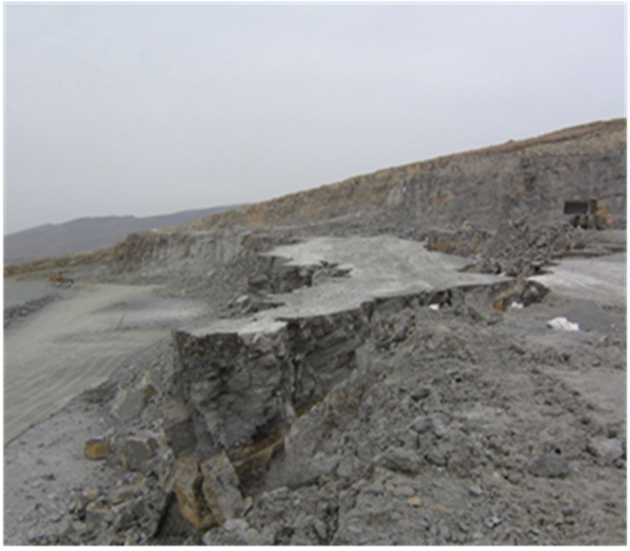

Fig. 2. Slide dimension of the study area

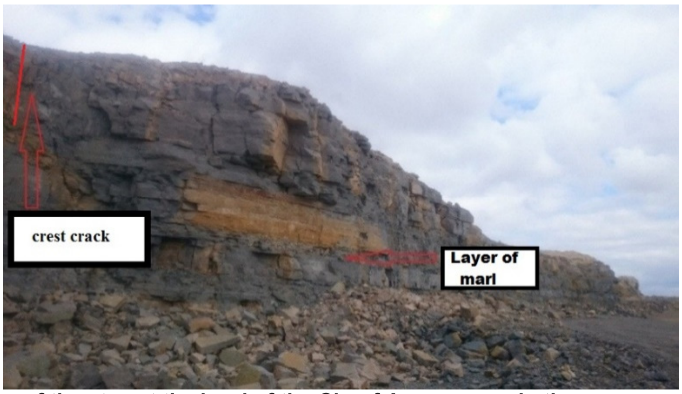

Fig. 3. Formation of the step at the level of the Chouf Amar quarry in the presence of a crest crack

The critical configuration is the development of the exploitation process in the critical geological condition, which lead to a general instability on the whole, accentuated by the orientation of the discontinuity (in the direction of the works). A marl intercalation is added to the building, which considerably increase the slope instability because that last has a tendency to lose its characteristics in presence of water (soap layer), as shown in the (fig. 4).

After analyzing the geological sections in the study area, we noticed the presence of an intercalation of marl layers between limestone formations with a direction parallel to the slope; this configuration has been mentioned as a geological condition favourable to the triggering of a sliding. According to (*Cruden and Varnes, 1996*) and several other studies, therefore, it is necessary to use the Geologic Structure Data for Slope evaluation.

Water infiltration in this sensitive geological formation (marl) is another essential factor, which has been the cause of a several disruptions *(Fleurisson et al., 2014*).

Moreover, blasting that generates seismic detonation waves which have been a continual problem for the slope stability and the public living near the mining operation must also be analysed according to Evgueni's recommendations (*Keefer, 1984*). This effect has the recorded measurements of different seismograph in the area so the object of our studies has been exploited. Finally, the operation's orientation and the position of the quarry opening were taken into consideration. This approach is used to understand the mechanism of rupture and to prevent a possible slide similar to that of the year 2004.

Collected Data. *Geological Data*. The first operation carried out is the dip measurements of the layers by an inclinometer of a geologist's compass. The obtained values have been classified according to the appropriate areas at their levels as follows:

1. In levels 1020, 1035, 1050 (area of limestone formation C1 their dip ranges from 8° to 10°).
2. In the levels 1000, 980, 960, 940, 920 (area of limestone formation C2 their dip 20°).
3. In levels 900, 880, 840 (area of limestone formation C3 there dip18°).

Calculation and Estimation of the Internal Friction Angle and Cohesion. To achieve our purpose, we had to collect a certain amount of information concerning the rocks constituting the slope needed (angle of internal friction, cohesion etc.) For the marl, we could count on the National Higher School of Mines and Metallurgy-Annaba- laboratory to carry out the necessary tests.

Cohesion and internal friction angle of the marl using a direct shear test. The shear test was carried out in the mine laboratory. The table 1 below summarizes all the obtained results.

Estimation of internal friction angle and the cohesion of limestone of the Chouf-Amar quarry. The estimation of cohesion and internal friction angle of our limestone rock massif in the Chouf Amar quarry is determined by two criteria which are Structural coefficient of weakening (*Ameratunga et al., 2016*), and Mohr Coulomb using Hoek-Brown classification of the rock massif (table 2).

Fig. 4. Wet marl layer

Table 1

Cohesion and internal friction angle of the marl values

		Sample 1	Sample 2	Sample 3	Medium
Case drained	Cohesion (KPa)	48,6	42,97	45,64	45,74
(Dry marl)	Internal friction angle Φ (°)	21,15	18,88	19,81	19,95
Case not drained	Cohesion (KPa)	25,06	26,52	22,29	24,62
(Wet marl)	Internal friction angle Φ (°)	17,64	17,01	16,17	16,94

Table 2

Cohesion and internal friction angle by two estimation methods

			Layer 1	Layer 2	Layer 3
Rock massif of limestone	Criterion of Hoek and Brown and Mohr Coulomb	Cohesion (MPa)	0,512	0,445	0,463
		Internal friction angle Φ(°)	29,68	27,21	27,93
	Structural weakening coefficient method	Cohesion (MPa)	0,54	0,62	0,73
		Internal friction angle Φ(°)	29,15	29,15	29,15

According to the obtained results, there's a discrepancy related to the estimation method, but, on the whole, they gave close values. In our calculation, we used the results obtained by criterion Mohr Coulomb with the help of Hoek and Brown classification as it gives a correlation over 99 %.

Calculation of safety factor Fs. The main objectives of a slope stability analysis include assessing the risk of rupture through the calculation of the overall safety factor for a slope and locating along the slide surface the areas, which have strong rupture potential on the other hand.

Slope stability is usually analysed by limit equilibrium methods (*Cho and Lee, 2001; Cai and Ugai, 2004; Rahardjo et al., 2007; Huang and Jia, 2009*), but these calculation methods assume that the land behaves like a solid which obeys the classical laws of rupture by shear. The formulas extracted from (*Pariseau, 2006*), in our case the calculation of the safety factor (Fs) of the different cases is calculated using Excel programme.

Bench with marl intercalation. The results are summarized in the following table 3.

Table 3

Parameters results for the safety factor calculating

Bench (level)	Highofthebench H (m)	Thehightothemarllayer h (m)	Theslopeangle ψ_f (°)	Dippingofthemarl layer ψ_P(°)	Z critical (m)	b critical (m)	Surface of slide A (m^2)	Weight Volume W (KN/m^3)
1050	20	20	80	8	16,857	22,271	22,609	11590,79
1035	15	15	80	10	12,402	15,101	14,927	5863,26
1020	15	15	80	8	12,642	16,659	16,956	6505,34
1000	20	20	80	20	14,687	13,103	14,203	6462,26
980	20	20	80	20	14,687	13,103	14,203	6462,26
960	20	20	80	20	14,687	13,103	14,203	6462,26
940	20	20	80	20	14,687	13,103	14,203	6462,26
920	20	20	80	20	14,687	13,103	14,203	6462,26
900	20	20	80	18	15,248	14,671	15,376	7361,49
880	20	20	80	18	15,248	14,671	15,376	7361,49
860	20	20	80	18	15,248	14,671	15,376	7361,49

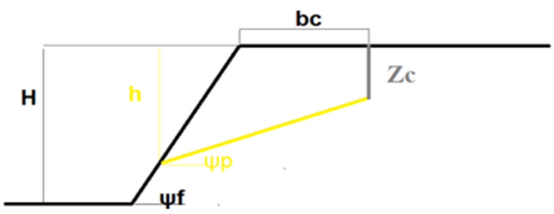

Fig. 5. Diagramsrepresentthecrestcrackin a slope

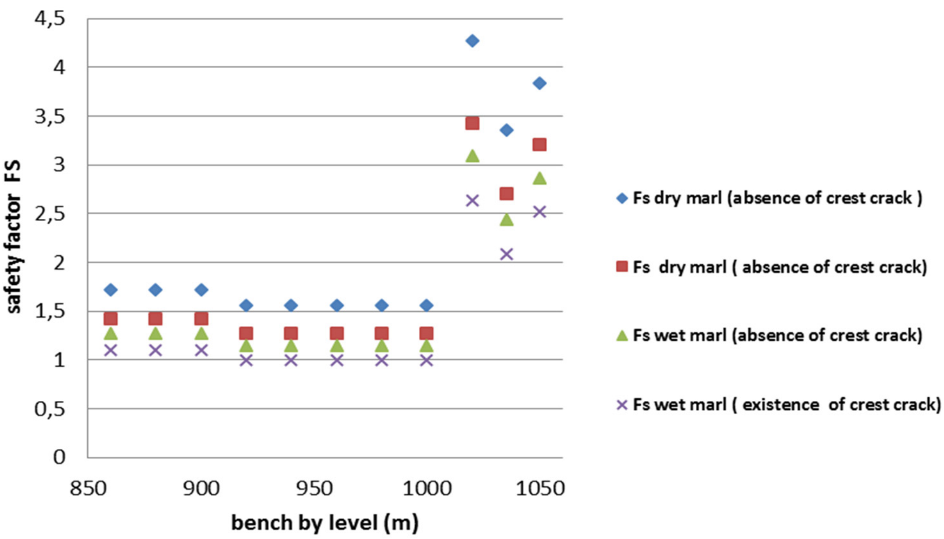

Fig. 6. Results of the parameters to calculate Fs in the case of existence of the crack crest

When the value of the existence depth (see (fig. 5)) of marl layer (h) in the slope face takes the step height value (H), the safety factor (Fs) assumes minimum values as shown in the (fig. 6).

There is the relationship between composite slope angles versus slope height which were derived the critical lithological state, where a big stability in the levels 1020, 1035 and 1050, less than in the other levels. This stability is caused by the slide surface A increasing, comparing to the crest crack existence case.

Blasting effect. (*Crandell, 1949*) recommends using the ratio $(\frac{a^2}{f^2})$, which is proportional to the kinetic vibration energy (*Panet and Caracilli, 1969*):

$$Ec = \frac{1}{2}\,m.v^2 = (\frac{1}{2}.\frac{m}{4.\pi^2})(\frac{a^2}{f^2}),$$

Where v – the maximum velocity vibration (m/s); A – the maximum acceleration vibration (m/s^2); F – vibrations' frequency (Hz).

Measurements on the ground of speed and seismic waves are frequently made with a seismograph. The maximum acceleration's vibration and seismic coefficients are shown in the following table 4.

In our case study, we'll use the largest value (of the 100 m station) because it influences stability, which is far more important.

Table 4

Particle Measurements with a seismograph and seismic coefficient value K

Measuringdistance	100 meters	500 meters
Seismic wave speed v (mm/s)	6,9	4,46
Frequency of the seismic wave f(Hz)	14,2	9,8
The maximum vibration acceleration a (m/s^2)	0,615	0,274
Seismic coefficient K	0,062	0,027

Normal state (dry marl). The safety factors presented for the case of the dry marl in the existence and absence of crest crack to well show the variation of safety factor Fs.

It is important to note that in the dry marl case, the effect of the seismic wave caused by the blasting has an influence on the Fs such as that in the existence of the crest crack case. There is instability except on the bench of the Levels 1020, 1035 and 1050. Moreover, in the absence of a crest crack there is a decrease in Fs but the benches are stable despite the blasting effect.

Critical state (wet marl). In the wet marl case, the quarry is in a critical state of stability, especially on the levels (1000, 980, 960, 940,920). This problem requires a study on the blasting effect. The results of calculations are presented in the following curves.

The results of the slope-stability analyses in this configuration under static and blasting conditions indicate that the designed ore side-slopes will be unstable.except those in the Level 1020, 1035, 1050.

The seismic coefficient in the blasting case is evaluated from (ks = 0.0627) at a distance of 100 meters, which can become larger in closer distance (possibility of taking the value of coefficient which is related to the earthquake ks = 0,1).

The seismic waves produced outside the blasting have a great impact on the safety factor (Fs), as (fig. 7) shows the decrease of Fs in each step.

Limestone step without consideration to marl intercalation. In the quarry, there is a certain step with low dip of marl intercalation in the Western part, an evaluation of the stabilities, the steps in the levels 1020, 1035 and 1050 (fig. 8) are the biggest, they have been chosen to get a general idea on the Fs of this case, the obtained results show that they are very stable.

To make the calculations, we need the following parameters: γ_r = 26,7 KN/m^3, c = 512 KPa, Φ = 29,68°, ψ_f = 70°.

The rupture critical plane angle has been calculated, according to (*Wyllie and Mah, 2004*) (table 5).

In the dip of the weak marl layer case, the limestone steps are stable in the normal state or under the effect of the blasting.

Solutions and Recommendations. It is strongly recommended to start all the interventions by the top of the quarry, progressing down more precisely, it is suggested to open the necessary trenches to redirect the exploitation from East-west axis to West-East, as shown below (fig. 9).

In the first phase, it is proposed to leave a heap of blasting (against weight) in the north direction to decrease the risk of slide before advancing from West to East. In the end, the reliability of solution is ensured by the creation of a drainage system to prevent water infiltration.

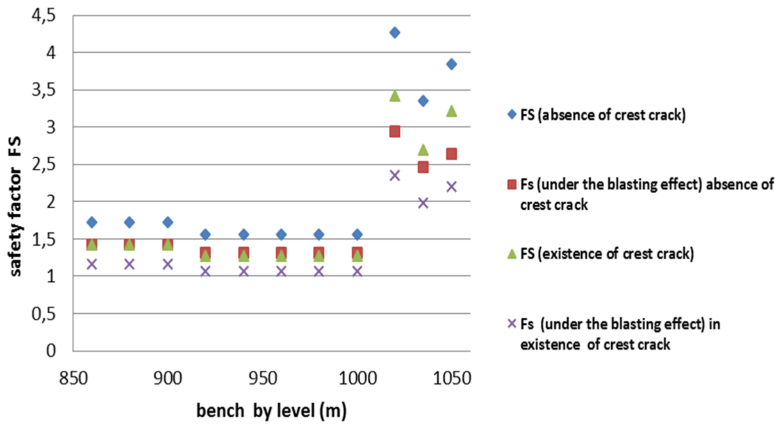

Fig. 7. Safety factors' results

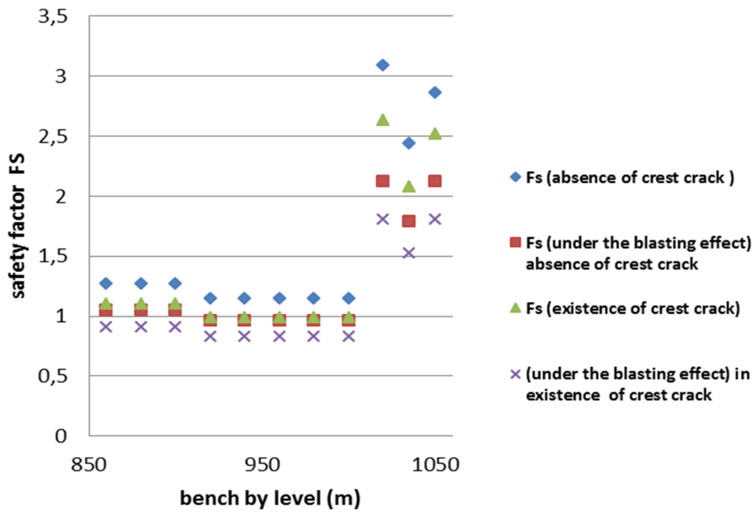

Fig. 8. Results of the safety factors under the influence of blasting in the case of wet marl

Table 5

Parameters' calculation and safety factor (limestone without marl intercalation's case)

Bench (level)	Z critique (m)	b critique (m)	A (m^2)	W (KN/m^3)	Fs	Fs (seismic case ks = 0,1)
1020	9,178	6,342	12,627	2169,927	3,819	3,548

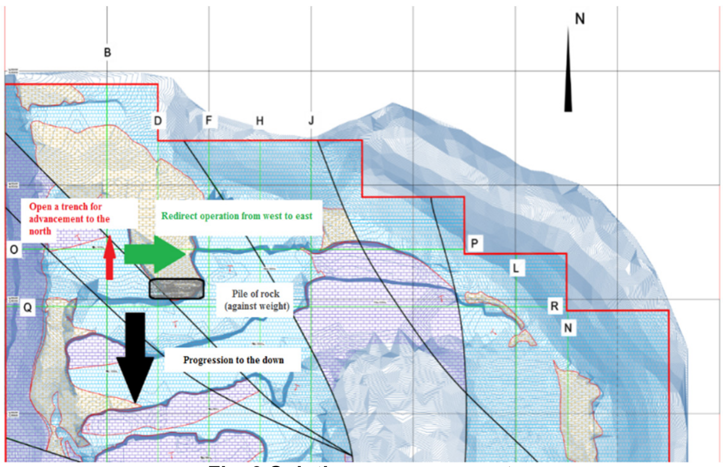

Fig. 9 Solution processors set

Conclusions. The acquired experience during this study shows that a particular precaution mainly related to the behaviour of the mining slope must be taken.

From the obtained results we can draw the following conclusions:

1. The physico-mechanical parameters of the strata are of poor quality and this has been observed from the drained and undrained case.

2. Measurements using a geologist's compass show that the marl diapers vary from 8° to 20° according to their position in the limestone formations (Layer 1, Layer 2, Layer 3).

3. Blasting at the Chouf Amar quarry produces seismic waves, which confirmed to have a significant influence on the quarry site, where the seismic coefficient obtained at a distance of 100 meters from ks = 0.0627 can become larger in a closer distance (Possibility of taking the coefficient value related to the earthquake ks = 0,1).

4. The mechanical and physical properties of the marl have shown to be highly altered by water infiltration.

5. In case of weakness of the marl layers dip, the limestone benches are stable in the normal state or under the effect of blasting.

In the light of these results, it becomes clear that the operational direction should be changed to avoid all the potential risks of land slide, putting potential workers and mobile equipment at risk. This progression change has demonstrated some complications mainly due to the fault zones; the counter force pile is one of the proposed solutions for all the fronts of size at risk.

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ОЦІНКА СТІЙКОСТІ СХИЛУ У ВІДКРИТОМУ КАР'ЄРІ В ХАММАМ ДАЛАА (МСИЛА, АЛЖИР)

Метою даного дослідження є визначення основних факторів, що впливають на стабільність майданчика, за допомогою адекватних рішень, які допомагають розв'язати проблеми стійкості схилів у кар'єрі Chouf Amar, Hammam Dalaa, Алжир.

Було зібрано велику кількість геологічних, гідрогеологічних і механічних даних, здійснено дослідження впливу різних факторів на коефіцієнт безпеки.

Методи граничних рівноваг було адаптовано для аналізу продуктивності існуючої площі виробничого майданчика з урахуванням мінливості даних.

Результати досліджень за різних конфігурацій виявили, що на показник стійкості сильно впливають гідравлічний та сейсмічний фактори.

Ключові слова: стабільність нахилу, гранична рівновага, коефіцієнт безпеки.

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ОЦЕНКА СТОЙКОСТИ СКЛОНА В ОТКРЫТОМ КАРЬЕРЕ В ХАММАМ ДАЛАА (МСИЛА, АЛЖИР)

Целью данного исследования является определение основных факторов, влияющих на стабильность площадки, с помощью адекватных решений, которые помогают решить проблемы устойчивости склонов в карьере Chouf Amar, Hammam Dalaa, Алжир.

Было собрано большое количество геологических, гидрогеологических и механических данных, проведено исследование влияния различных факторов на коэффициент безопасности.

Методы граничных равновесий были адаптированы для анализа производительности существующей площади производственной площадки с учетом изменчивости данных.

Результаты исследований при различных конфигурациях показали, что на показатель устойчивости сильно влияют гидравлический и сейсмический факторы.

Ключевые слова: стабильность наклона, предельное равновесие, коэффициент безопасности.