

Modeling of the effect of explosives and geological and geotechnical parameters on the stability of rock masses

Case of the Marrakech - Agadir highway, Morocco

T. Benchelha⁽¹⁾, T. Remmal⁽¹⁾, R. El Hamdouni⁽²⁾, H. Mansouri⁽³⁾, H. Ejjaouani⁽³⁾, H. Jounaid⁽¹⁾, S. Benchelha⁽¹⁾

Abstract—During the earthworks for the construction of Marrakech-Agadir highway in southern Morocco, which crosses mountainous areas of the High Western Atlas, the main problem is the stability of the slopes. Indeed, the use of explosives as a means of excavation associated with the geological structure of the terrain encountered can trigger major ruptures and cause damage which depends on the intrinsic characteristics of the rock mass.

The study consists of a geological and geotechnical analysis of several unstable zones located along the route, mobilizing millions of cubic meters of rock, with deduction of the parameters influencing slope stability.

From this analysis, a predictive model for rock mass stability is carried out, based on a statistic method of logistic regression, in order to predict the geomechanical behavior of the rock slopes constrained by earthworks.

Keywords—Explosive, logistic regression, rock mass, slope stability.

I. INTRODUCTION

THE geological environment and the mechanical properties of rock slopes are deciding factors in the stability of the environment after excavation. There are many external disturbances that can trigger landslides [1] : (1) an increase in the slope angle, (2) an increase in the load on the slope, (3) shallowing of the water table and the associated pressure, (4) the slope under earthquake loading.

The multiplicity of geomechanical properties is always predetermined by the geological structure of the massif under consideration [2]. Detailed knowledge of the fracture system affecting a rock mass is essential for analysing the conditions that allow deformation and rupturing to occur. Attention must be paid to directional families of discontinuities, their classification and degree of connectivity, and their geometric and geotechnical parameters.

The objective of this paper is to identify the parameters influencing the stability of the rock slopes and to evaluate the impact of each of them. The example chosen in this case, is the Imintanout – Argana section of the Marrakech–Agadir highway. The lithological and structural aspects of the slope have been identified by considering the regional geological setting to explain the rock mass breakout conditions.

⁽¹⁾ GAIA Laboratory. Hassan II University. Ain Chock Sciences Faculty. Casablanca. Morocco. (phone: 212-661-866-247, E-mail : taoufik.benya@gmail.com, tremmal@yahoo.fr, jounaidhalima@gmail.com, said1.benchelha@gmail.com)

⁽²⁾ Civil Engineering Department. ETSICCP. Granada University. Campus Fuentenuova, s/n. 18071-Granada. Spain. (E-mail: rachidej@ugr.es)

⁽³⁾ Laboratoire Public d'Essai et d'Etudes (LPEE). Casablanca. Morocco. (Email :ejjaouani@lpee.ma, hamoumansouri@yahoo.fr)

II. REGIONAL GEOLOGICAL SETTING

The section Imintanout-Argana (Fig.1), crosses regions of different morphology. Thus, the first section of the highway crosses the northern subatlantic zone and the axial zone of the High Atlas. It consists mainly of Cenozoic and Mesozoic terrains composed of conglomerates, limestones and marls. The second section is located in the Argana Triassic Basin. Lithologically, this comprises a thick, monotonous, wine to red-coloured detrital series that includes, from bottom to top, conglomerates, red sandstones, alternations of mudstones, argillites, and locally saliferous marls. At the top of the succession, doleritic basalt flows indicate the beginning of the Atlantic Ocean extension [3].

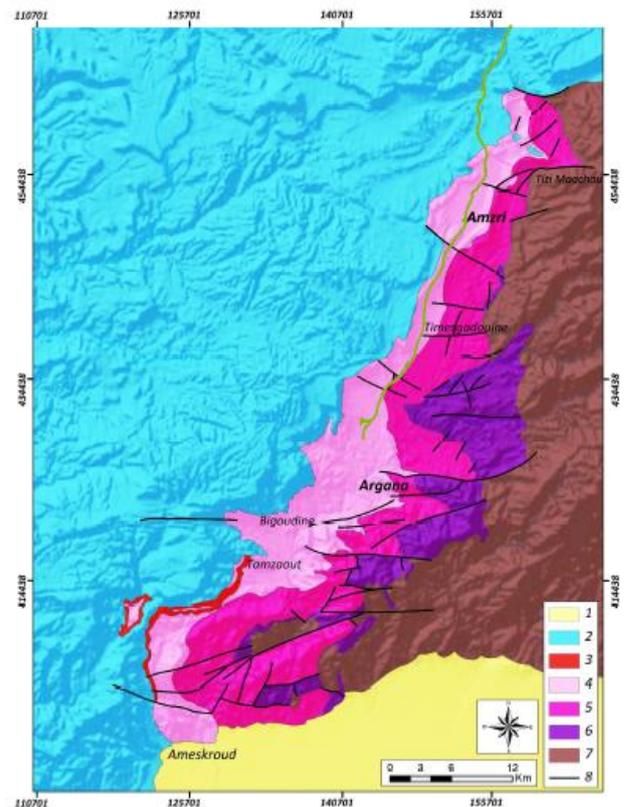


Fig. 1 : Geological setting of the Imintanout-Argana section of the Marrakech-Agadir highway (T.Benchelha et al., 2016)

III. PARAMETERS AFFECTING THE SLOPE STABILITY

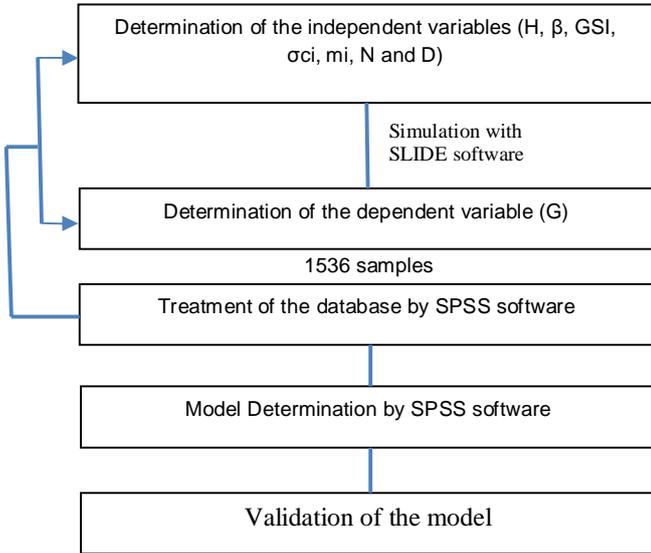
Identification of factors influencing slope stability requires prior knowledge of the main causes of landslides [4].

The independent variables used in this study are :

- Height of slope (H): this value represents the maximum slope height. It varies between 10 and 200 m;
- Slope (β): this is the angle that the slope makes with the horizontal. It is between 0 and 90 °;
- Geological Strength Index (GSI): this value is determined from geomechanical stations and in-situ surveys. It varies between 10 and 100.
- Intact rock compressive strength (σ_{ci}): this parameter is obtained from the mechanical tests on intact rock carried out in the laboratory,
- Hoek-Brown constant (m_i): This parameter is determined from the triaxial tests. Its value varies between 5 and 35;
- Disturbance parameter (D): This parameter describes the implementation quality of the explosives. It takes the value 1 in the absence of explosives, 2 in the case of better use of explosives and 3 in the case of improper use of explosives.
- Water table (N) : This dichotomous parameter describes the presence (1) or the absence (0) of the aquifer at the place studied;

The dependent variable (G) is dichotomous and takes the value of 1 when the slope safety coefficient is less than 1 (unstable slope), and 0 when the slope safety factor is greater than 1 (stable slope).

IV. METHODOLOGY OF ANALYSIS



In order to define the predictive model of the unstable slopes at the study area, several simulations have been carried out using the SLIDE software [5] and the simplified method of Bishop [6]. From these simulations, 1536 samples, containing information on independent variables (H, β , GSI, σ_{ci} , m_i , N and D) and the dependent variable (G), were collected and then introduced into the SPSS software (Statistical Package for Social Sciences [7]) for treatment.

Modeling is carried out by the logistic regression method

expressed by :

$$P(G=1/X) = \frac{1}{1 + e^{-C(X)}}$$

When : $C(X) = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n$

The design of the forecast model is based on the 1536 samples, while its validation is based on data from 38 excavated material located in the study area.

V. MODELING BY REGRESSION LOGISTIC METHOD

The objective of this section is to identify the variables that most likely predict the probability of having a landslide (G). An evaluation of the effect of the parameters (H, β , GSI, σ_{ci} , m_i , N and D) is carried out. Five predictive variables evaluated are continuous (H, β , GSI, σ_{ci} , m_i) and two variables are categorical (N and D).

Tab.1 shows that as far as a new variable is introduced, it contributes significantly to improving the model.

The evaluation of the model is done through the Wald statistic that illustrates the difference in the model before and after the addition of the last variable. It is observed that in the final step, all the coefficients are significant, even when several variables are introduced.

		A	E.S.	Wald	ddl	Sig.	Exp(B)	IC for Exp(B) 95%	
								inferior	Superior
Step 1 ^a	GSI	-.073	.005	250,058	1	.000	.930	.921	.938
	Constant	1,045	.132	62,576	1	.000	2,843		
Step 2 ^b	H	.027	.003	114,317	1	.000	1,028	1,023	1,033
	GSI	-.086	.006	232,896	1	.000	.917	.907	.928
Step 3 ^c	Constant	-.386	.190	4,126	1	.042	.680		
	H	.035	.003	122,266	1	.000	1,035	1,029	1,041
Step 4 ^d	GSI	-.107	.007	213,837	1	.000	.899	.886	.912
	D	1,562	.150	107,743	1	.000	4,768	3,550	6,404
Step 5 ^e	Constant	-3,674	.396	86,143	1	.000	.025		
	H	.041	.004	125,694	1	.000	1,041	1,034	1,049
Step 6 ^f	GSI	-.125	.009	201,040	1	.000	.883	.868	.898
	D	1,839	.176	109,704	1	.000	6,293	4,460	8,879
Step 7 ^g	N	2,164	.254	72,739	1	.000	8,704	5,294	14,312
	Constant	-5,412	.507	113,833	1	.000	.004		
Step 8 ^h	H	.051	.005	123,618	1	.000	1,053	1,043	1,062
	Sigmaci	-.040	.005	75,772	1	.000	.960	.952	.969
Step 9 ⁱ	GSI	-.157	.012	173,693	1	.000	.855	.835	.875
	D	2,320	.219	112,727	1	.000	10,180	6,633	15,624
Step 10 ^j	N	2,759	.312	78,372	1	.000	15,780	8,568	29,065
	Constant	-4,643	.565	67,583	1	.000	.010		
Step 11 ^k	H	.069	.007	112,505	1	.000	1,072	1,058	1,086
	Béta	.120	.014	70,284	1	.000	1,127	1,096	1,159
Step 12 ^l	Sigmaci	-.054	.006	79,429	1	.000	.947	.936	.959
	GSI	-.212	.018	139,393	1	.000	.809	.781	.838
Step 13 ^m	D	3,139	.306	105,123	1	.000	23,089	12,670	42,076
	N	3,715	.412	81,453	1	.000	41,067	18,327	92,022
Step 14 ⁿ	Constant	-13,298	1,355	96,385	1	.000	.000		
	H	.079	.008	105,973	1	.000	1,082	1,066	1,099
Step 15 ^o	Béta	.136	.016	70,676	1	.000	1,146	1,110	1,183
	Sigmaci	-.062	.007	78,476	1	.000	.940	.927	.953
Step 16 ^p	GSI	-.241	.021	125,698	1	.000	.786	.753	.820
	mi	-.088	.016	31,157	1	.000	.916	.888	.945
Step 17 ^q	D	3,574	.357	100,036	1	.000	35,642	17,694	71,794
	N	4,231	.472	80,362	1	.000	68,798	27,278	173,514
Step 18 ^r	Constant	-13,387	1,473	82,585	1	.000	.000		

Tab. 1 : Variables in the equation (SPSS software)

The sign of the b_i coefficients indicates the direction of the relationship between the predictive variation and the independent variable. The relationship is positive for the variables H, β , D and N, which means that when the value of these parameters increases, the probability of having a slip increases and vice versa.

The ROC curve (Fig. 2) aims to compare the classifier or

the proposed model with the trivial model. It is based on two main elements:

- Sensitivity: this is the rate of true positives, i.e. the proportion of positive "good" estimates or the likelihood of having a sliding knowing that there is slippage. This parameter is presented in ordinates of the ROC curve.
- Specificity: this is the rate of true negatives, that is, the proportion of negative "good" estimates. The ROC curve presents the parameter (1-Specificity), which presents the false-positive rate or the probability of having a sliding knowing that there is no slip. This parameter is shown on the x-axis.

The area under the diagonal curve is 0.5, while the area under the ROC curve shows the performance index of the model.

Tab. 2 shows the area under the ROC curve that is equal to 0.992 well above 0.5, which represents the random classifier.

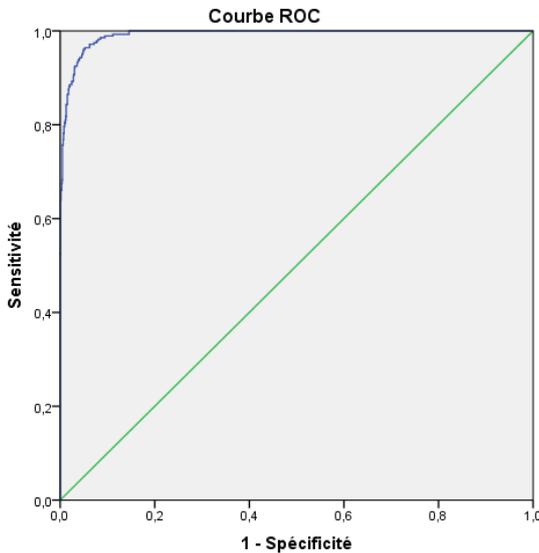


Fig. 2 : ROC curve

Zone	Erreur Std. ^a	Signif. asymptotique ^b	Intervalle de confiance 95% asymptotique	
			Borne inférieure	Borne supérieure
	.992	.002	.989	.995

Tab. 2 : Area under the ROC curve

VI. VALIDATION OF THE MODEL

From *Tab.1*, the formula chosen, giving the probability of having a slip as a function of the independent variables, is as follows :

$$P = \frac{1}{1 + \exp[-(0.079 * H + 0.136 * \beta - 0.062 * \sigma_{ci} - 0.241 * GSI - 0.088 * m_i + 3.574 * D + 4.231 * N - 13.387)]}$$

This model was applied to the 38 excavation located at the study area for validation. The results obtained are summarized in *Tab.3*.

Analysis of these results (*Tab.4*) shows that 92% of the

slides are classified correctly.

Excavation n°	H (m)	β (°)	σ_{ci} (Mpa)	GSI	m_i	D	N	P	$G_{theoretical}$	G_{real}
1	14.3	79	50	45	8	3	1	0.23	0	0
2	20.3	79	50	46	8	3	1	0.27	0	0
3	13.5	45	50	40	17	3	1	0.00	0	0
4	14	56	50	40	8	3	1	0.04	0	0
5	19.2	45	50	40	8	1	1	0.00	0	0
6	100	63	50	35	8	3	1	1.00	1	1
7	100	63	50	35	8	3	1	1.00	1	1
8	65.4	56	50	55	8	1	1	0.00	0	1
9	50.7	76	50	36	8	3	0	0.31	0	0
10	12.3	63	50	37	8	3	1	0.17	0	0
11	17.3	63	50	40	8	3	1	0.13	0	0
12	11.3	34	50	55	8	3	1	0.00	0	0
13	12.1	79	50	37	17	1	1	0.00	0	0
14	25	79	50	42	8	1	1	0.00	0	0
15	25	79	50	57	8	1	1	0.00	0	0
16	19.5	45	50	57	8	3	1	0.00	0	0
17	40	45	50	40	8	3	1	0.07	0	0
18	31.4	45	50	50	8	3	1	0.00	0	0
19	120	63	50	50	8	3	1	0.98	1	1
20	70	79	50	45	8	3	1	0.96	1	0
21	29.3	72	50	45	8	3	1	0.27	0	0
22	29.3	79	50	60	8	3	1	0.03	0	0
23	29.3	63	25	53	7	3	1	0.08	0	0
24	17.9	63	50	58	17	3	1	0.00	0	0
25	100	63	25	40	7	3	1	1.00	1	1
26	100	63	25	40	7	3	1	1.00	1	1
27	10	63	25	40	7	3	1	0.29	0	0
28	12.4	63	25	40	7	3	1	0.33	0	0
29	14.2	45	25	40	7	3	1	0.05	0	0
30	30.8	45	25	52	7	3	1	0.01	0	0
31	10.3	27	25	43	7	3	1	0.00	0	0
32	24.3	27	25	38	7	3	1	0.02	0	0
33	18.5	79	25	40	7	3	1	0.88	1	0
34	10.4	45	25	40	7	3	1	0.04	0	0
35	18.7	27	50	44	17	3	1	0.00	0	0
36	18.7	45	25	43	7	3	1	0.03	0	0
37	13.1	79	50	40	17	3	1	0.29	0	0
38	10.2	27	25	47	7	3	1	0.00	0	0

Tab. 3 : Validation results

Observations	Forecasts		Correct percentage
	Sliding	Correct	
Sliding 0	30	2	94
Sliding 1	1	5	83
Global percentage			92

Tab. 4 : Classifying table

VII. CONCLUSION

The results of the statistical analysis by logistic regression applied to the layout of the Marrakech-Agadir motorway, has identified the most influential parameters in the sliding rock slope dotted along this route.

The presence of the web (N = 1) and the use of explosives (D = 1) are the factors having the greatest impact on the stability of the rock mass, compared to the parameters (H, β , GSI, σ_{ci} , m_i) that show an influence of lesser importance.

The use of the function, deduced from the logistic regression model and confirmed by the validation tests ([8]; pseudo R2 and ROC curve) shows that the critical height

corresponding to a limit stability ($FS = 1$) can be reduced by about 80% when earthworks use explosives. This decrease varies according to the resistance parameters of the rock mass in situ and according to the slope geometry.

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