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SLOPE BEHAVIOUR IN HIGHWAYS: A DECADE OF DETERIORATION IN METAMORPHIC ROCKS WITH VOLCANO-SEDIMENTARY ORIGIN ALONG THE IP4 (NE PORTUGAL)

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PALAVRAS-CHAVE: taludes artificiais, estabilidade, deterioração, factores, unidades vulcano-sedimentares, detritos.

KEY WORDS: artificial slopes, stability, deterioration, factors, volcano-sedimentary units, debris.

ABSTRACT

A decade after the opening of the IP4 (principal itinerary Porto-Bragança) between Mirandela and Macedo de Cavaleiros, it is stimulating and possible to evaluate the amount of rock material removed from the excavated slopes, in the intermediate to low grade metamorphic Lower Palaeozoic rock units along a segment of twenty kilometres. These units comprehend the quartzphyllites, greenstones and greenschists, metarhyolites and metamorphic tuffs and tuffites of a broad synform.

The deterioration types, the volume of the debris, the major dimension of the rock fragments and the length of deteriorated sites are evaluated against the rock types, the density, orientation and opening of the discontinuities, degree of weathering, geometry of the slope and the prevalent foliation. The deterioration susceptibilities (RDA+e) found for the whole length of these highway slopes, range from 54 to 99 (the full interval ranges from 6 to 160). It can be tested against an attempted index of actual deterioration of the slopes (ADS) which is found to range between 8 and

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18 (the full interval is 4 to 20). It has been found that these two indices show a positive correlation expressed as $ADS = 0,26RDA - 5,64$ for an $R^2 = 0,56$. If it were used the (RDA+e), the correlation would be worse. The most deteriorated segment is located in the thermally recrystallized and preferentially fractured volcano-sedimentary units that crop out in the western limb of the Romeu antiform.

RESUMO:

O comportamento de taludes de rodovias: uma década de deterioração em rochas metamórficas de origem vulcano-sedimentar ao longo do IP4 (NE Portugal)

Uma década após a abertura do troço do IP4 entre Mirandela e Macedo de Cavaleiros (itinerário principal Porto-Bragança) é estimulante avaliar a quantidade de material rochoso caído dos taludes escavados em rochas metamórficas do Paleozóico Inferior, numa extensão de vinte quilómetros. Estas unidades compreendem quartzofilitos, xistos verdes, metarriolitos, tufos metamórfico e tufitos de uma sinforma aberta.

Os tipos de deterioração, o volume de detritos, a dimensão dos maiores fragmentos rochosos e a extensão dos locais deteriorados foram avaliados tendo em atenção o tipo de rochas, a densidade, a orientação e abertura das descontinuidades, o grau de alteração, a geometria do talude e a foliação predominante. As susceptibilidades de deterioração (RDA+e) encontradas para a extensão total destes taludes situam-se no intervalo 54 a 99 (o intervalo total varia entre 6 e 160); foram testadas contra um índice de deterioração real dos taludes, aqui proposto como ADS, o qual varia entre 8 e 18 (o intervalo total vai de 4 a 20). Os índices RDA apresentam uma correlação positiva que se expressa como $ADS = 0,26RDA - 5,64$ para um $R^2 = 0,56$. Se fosse usado o (RDA+e) a correlação seria mais pobre. O segmento mais deteriorado encontra-se nas unidades vulcano-sedimentares, com recristalização de contacto e preferencialmente fracturadas, do flanco oeste da antiforma do Romeu.

INTRODUCTION

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The intrinsic qualities of the rock slope foundations and the type and classes of instabilities as well as the resulting collapsed rock materials thereon incident are closely related (PERRY & O'REILLY, 1990; GONZÁLEZ DEL VALLEJO *et al.*, 2002).

Consequent to the surveying of the machined slopes, along a 20 km segment of the highway IP4 (Porto – Bragança), carried by SÁ (1999), it is here shown some of the deterioration phenomena that have been found on the different units of a lithostratigraphic sequence, dated from the Lower Palaeozoic, which is

composed of phyllites-micaschists and their overlaying para-ophiolitic suite – greenstones, greenschists, metarhyolites, graded metavolcaniclastics and quartzphyllites.

As a matter of fact, the slopes and the road-way deterioration range from the visual impact to the complete blockade or even the induced failure of the road-way structure (SOBRINHO, 1988; ZIKA, 1990; BASKERVILLE *et al.*, 1993). It is here made an attempt to check the index of Rock Deterioration Assessment (RDA), which is here also evaluated with a slightly modified configuration, against the Actual Deterioration of the Slopes (ADS). In fact, it was possible to assess this deterioration ten years after the road cutting. The assessed indices can be obtained strictly on the basis of the visual characterisation of the slopes.

GEOLOGICAL SETTING AND THE COLLECTED DATA

The terrains herein envisaged, which belong specifically to the denominated Lower Allochthonous Thrust Complex (LATC) of the Galiza – Trás-os-Montes Zone (GTMZ), are composed of two lithologic suites; the Lower Unit is essentially made of micaschists and the Upper Unit comprehends metamorphic rocks after a volcano-sedimentary sequence and its prograded acidic, intermediate and basic submarine flows and volcanoclastics (SÁ *et al.*, 2000a).

Upwards the LATC it is found the Ophiolitic Thrust Complex (OTC), with relevant affinities to the LATC. Here, from top to bottom, it can be seen the following sequence: greenstones (amphibolites), sheeted dyke complex of greenstones (amphibolites), flaser gabbros, melagabbros and serpentized lherzolites (RIBEIRO *et al.*, 1990).

As these highway slopes were excavated in early 1990's and the Rockslope Deterioration Assessment (RDA) was estimated in 1998, it was considered the need to assess the actual deterioration with a campaign of field work focused on the sites with previously determined values of RDA following NICHOLSON & HENCHER (1997). So, four parameters were considered (SÁ *et al.*, 2000b) and adequately dimensioned:

- a) the average spacing of the discontinuities;
- b) the average openings of the discontinuities;
- c) the strength of the rock mass;
- d) the degree of weathering.

For this particular case study, due to its rather anisotropic rock fabric, a fifth parameter was considered:

- e) the dihedral angle between the “slope plane” and the major discontinuity(ies) of the rock mass (Table 1).

Table 1 – Factors corresponding to the dihedral angle (5th parameter) between the slope plane and the major discontinuities of the rock mass.

	Value
> 50°	1
40° – 50°	3
20° – 40°	8
10° – 20°	15
< 10°	25

Table 2 – Susceptibility classes using RDA method vs. Susceptibility classes using RDA method and the 5th parameter (SÁ *et al.*, 2000b).

Site	ΣRDA	RDA Classes	5 th parameter	ΣRDA+e	Final Class
2	64	4	8	72	4
2A	70	4	3	73	4
3	66	4	1	67	4
3A	61	4	8	69	4
8	53	3	1	54	3
13	67	4	8	75	4
13A	66	4	15	81	5
14	67	4	8	75	4
17	69	4	3	72	4
18	82	5	1	83	5
19	83	5	3	86	5
19A	90	5	8	98	5
20	78	4	8	86	5
20A	85	5	1	86	5
21	84	5	15	99	5
25	77	4	8	78	4
25A	66	4	3	69	4
25B	75	4	3	78	4
26	65	4	1	66	4
27	65	4	3	68	4
29	62	4	8	70	4
34	75	4	3	78	4
39	79	4	1	80	5
46	63	4	3	66	4

The existence of discrete faults, as well as the technology used to make the road cut, and the height and tilt of the slopes are also used to compute the weighted sum that stands for the susceptibility index. Herein the deterioration susceptibilities fit within the interval 54 to 99 (the full interval ranges from 6 to 160).

The ADS index, which considers the factors (see Table 3):

- a) type of deterioration (rock fall, landslide, toppling and creep);
- b) length of the deteriorated slope;
- c) volume of the slided rock material;
- d) dimension (estimated weight) of the major blocks.

All these factors can be evaluated and classified very quickly during the field surveying and should be photographically recorded in order to make possible the relative analysis of the series of sites. This relative evaluation is necessary if the surveying is discontinuous and performed by several operators.

Table 3 – Indices of Actual Deterioration of Slopes (ADS), Rock deterioration Assessment (RDA) and transformed RDA (RDA+e). Legend for the factors of ADS. Type – Rock fall=4; Landslide=3; Toppling=2; Creep=1; the second factor counts with 50%; Length - <5 m=1; 5-10 m=2; >10m=3; Volume – considering the length of 25 meters, <1 m³=1; 1-5m³=2; 5-10 m³=3; 10-100 m³=4; 100-500 m³=5; Major block weight - <20 kg=1; 20-50 kg=2; 50-100 kg=3; >100 kg=4.

Site n.º	Type	Length	Volume	Block dim.	ADS	RDA	RDA+e
2	4	2	4	3	13	64	72
2A	4	1	2	1	8	70	73
3	5	3	4	2	14	66	67
3A	5	3	4	1	13	61	69
8	4	1	2	3	10	53	54
13	4	3	2	1	10	67	75
13A	4	3	2	1	10	66	81
14	4	1	2	2	9	67	75
17	5	2	3	3	13	69	72
18	5	3	4	2	14	82	83
19	6	3	5	4	17	83	86
19A	6	3	5	4	19	90	98
20	6	3	5	4	18	78	87
20A	6	3	5	4	18	85	86
21	5	3	5	3	16	84	99
25	5	3	4	3	15	77	78
25A	5	3	4	2	14	66	69
25B	5	3	4	3	15	75	78
26	5	3	4	3	15	65	66
27	1	2	4	2	9	65	68
29	1	2	4	3	10	62	70
34	6	3	5	3	17	75	78
39	5	3	6	3	17	79	80
45	1	3	3	3	10	63	66

If the RDA is modified to include the parameter e) which emphasises the role that the major joints or foliations play in the cases of rock fall and in some cases of landslides, the transformed RDA (RDA+e) shifts to higher values. The classes that were used for the new index have been maintained as they are used when the parameter is the classical RDA. In this case study only three sites (13A, 20 and 39) ought to be considered as shifted from the 4th to the 5th classes. There are clearly sites where the deteriorated type is in the group of the rock fall.

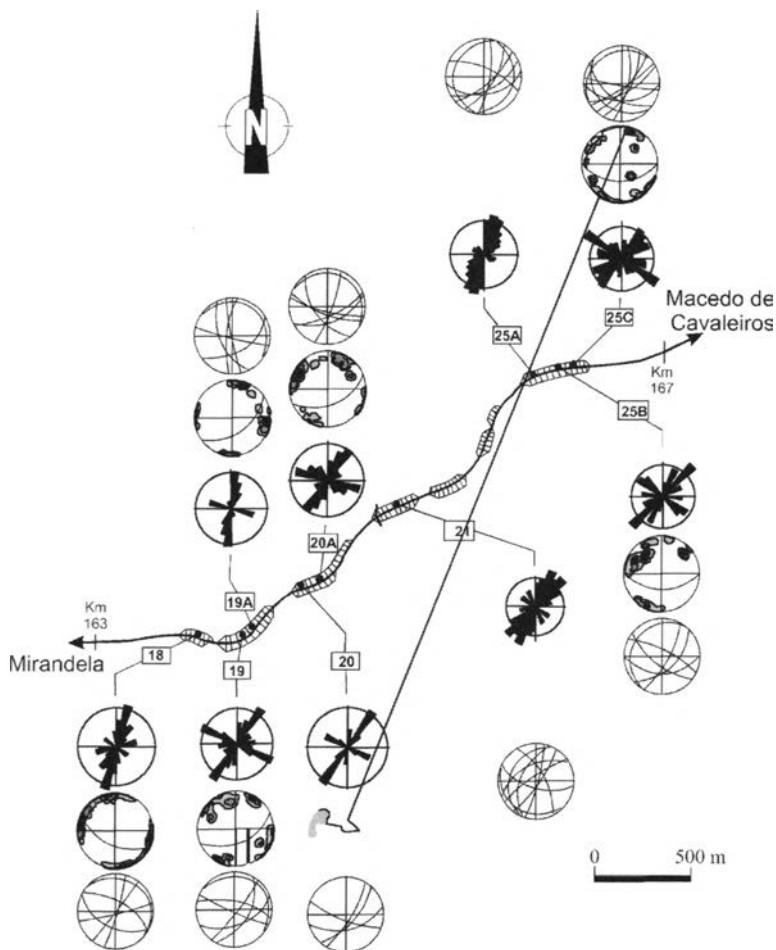


Fig. 1 – Segment of the highway between sites 18 and 25. The set of three stereograms made for each side shows a) density of the joint families; b) the density of joint plus the attitude of slope and c) attitude of major families of discontinuities (adap. SÁ, 1999).

In fact, it could have been an attempt to emphasise the role of the pair of the discontinuities that are more influential for the movement of the rock material.

It was expected that the reformulated RDA as RDA+e would give a better picture of the potential deterioration of the slopes.

The sites where the deterioration has been more active (consequently the RDA and ADS have the higher values – Tables 1, 2 and 3) have been telescoped from the overall map with the discontinuities (Fig. 1).

In this map are shown all the geometric features that should be considered in the processes of mechanical degradation of the rock slopes namely the azimuth and the dip of the slope, the major foliation of the metamorphic rocks, the geometry of the families of joints. The stereograms might be used to propose which are the joint sets potentially active, namely to induce the sliding of blocks controlled joints that make dihedral angles plunging to the slope.

CONCLUSIONS

The surveying of the IP4 highway slopes along a stretch of 20 km was intended for its detailed geological and geotechnical analysis, namely for the diagnosis of their instability. This survey gives a sound picture of the discrete sections with sizeable potential of risk. The risks are to be assigned to multiple classes, degrees of instabilities, and mechanisms of deterioration.

The evaluation of the susceptibility for deterioration and the also the assessment of the actual deterioration have been made with very simple techniques and with the minimum equipment. The cost of a study like this is to be taken into account. Furthermore, the factors used to evaluate the Rockslope Deterioration Assessment (RDA) rely on the observation that fairly trained geologist or engineer is qualified to carry on.

It is clearly emphasised that the mechanisms of deterioration and the grading of instability are strongly dependent from the geometry of the slope and from lithological and tectonic parameters. So, the expert geological identification and the forecasting of the behaviour, consequent to the petrographic, structural and weathering parameters, ought to be taken into account for the construction and maintenance of the road slopes – techniques and costs. They help to choose the geometry of the slope as well as their monitoring devices, the drainage and sustenance systems and the remediation techniques.

The evaluation of the deterioration susceptibilities of the highway slopes was made using the method RDA modified with a factor relative to the dihedral angle between the “slope plane” and the major discontinuity(ies) of the rock mass.

This geotechnical survey, which was made ten years after the highway construction, adds a good amount of information to the pre-construction surveying and to the forecast made five years after the road opening.

It is made clear that the most serious situations of deterioration occur in the high way slopes excavated in the volcano-sedimentary rock units (quartzphyllites with interlayered metarhyolites, namely where they show sulphides of exalative parentage), and also where the attitude of the mesoscopic tectonic structures is adequately oriented to maximize the deterioration mechanisms.

It is also clear that the southern slopes of the highway were properly shaped with steeper dips and without the “stairs” that appear to have been “carved” as a “mirror” image of those carved on the northern slopes, where they are really necessary.

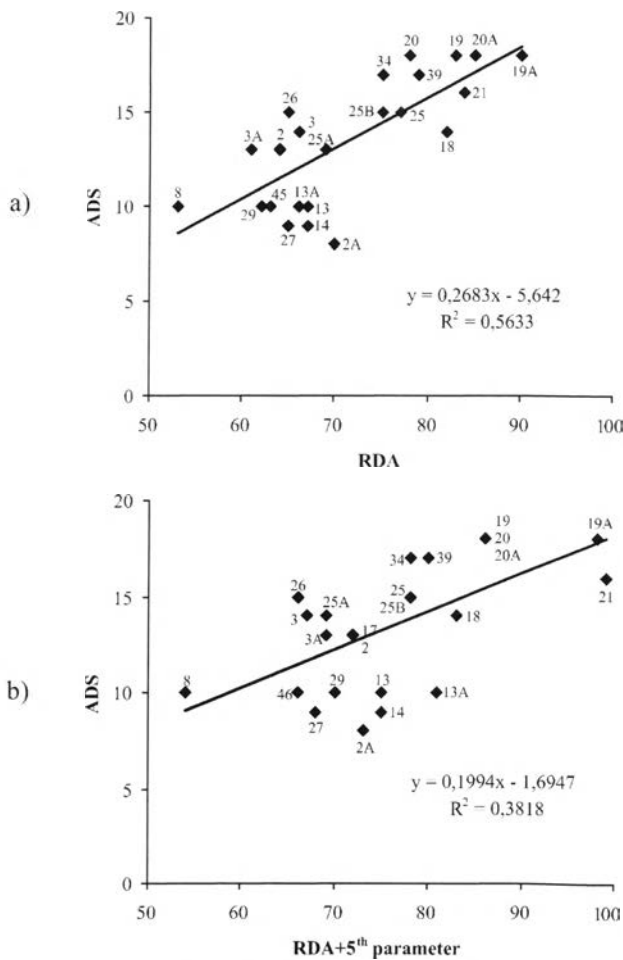


Fig. 2 – Correlation between a) on the top the index of Rockslope Deterioration Assessment (RDA) and the index of Actual Deterioration of the Slopes (ADS) and b) on the bottom the modified index of Rockslope Deterioration Assessment (RDA+e) and the index of Actual Deterioration of the Slopes (ADS).

If the pre-construction detailed and expert geological-geotechnical surveying is apt to optimize the road project, as well as its construction and maintenance, the prograding of the deterioration can be minimized if the new findings are incorporated in the "remediation prescription". This is much so as one takes into consideration the assessment of the parameters visualized on the rock materials detached from the slopes after the first decade of the slopes life.

In fact, it is here shown that the prospected vulnerability evaluated on the basis of the morphology of the slope, rock types, weathering degrees and the mechanical discontinuities of the rock units is positively correlated with the dimensioned rock masses detached from the highway slopes ($ADS=0,26RDA-5,64$ for an $R^2=0,56$) (Fig. 2).

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