Some aspects of andesitic Bimrock characterisation

T Jovanovska¹ and E Angelova²

¹Macedonian Association for Geotechnics, blvd. Partizanski odredi 24, 1000, Skopje, MKD
²Geohydroconsalting, Skopje, MKD

tamarajovr@gmail.com

Abstract. This paper describes an approach applied in the design and construction of one cut at section km 23+200 - km 23+400 from the expressway A4, section Stip – Radovish, part of the Macedonian road network in construction. The cut is constructed in volcanogenic rock mass of andesitic type, with different zones within the massif. It is specific, because of different phases of extrusions along wider fault zones, rock mass has typical composition of block-in-matrix (BIM) rocks. In the frame of this article, the approach based on the integral application of empirical – analytical, and observational methods during the design and construction is presented. Some results from investigations and correlations between the investigated parameters necessary to define optimal slope protection elements are also given. One attempt is done to prepare a simple tool for characterization of BIM rocks initially named as BIMSI (Block In Matrix Strength Index), based on a combination of Volumetric Block Proportion and Strength Ratio of significant blocks and matrix. This idea requires further study. Finally, some elements of applied solution for slope protection are presented.

1. Introduction

The practice in Rock Engineering shows that analyses for “block-in-matrix rocks” (BIM – rocks) rocks is a challenging task due to their complex structure and engineering behavior. Problems to be solved in such media are present in the process of investigations, design, and construction because, it is very difficult to define their extent in space, parameters for characterization, preparation of conceptual and numerical models due to the contrast in the strength between the blocks and the matrix material surrounding them, etc. The expression “block-in-matrix rocks” was introduced by Raymond [1]. It is related to similar terminologies such as mega-brecia’s, olistostromes, wildflysch, varicolored clays, and sedimentary chaos [2]. The term “bimrock” was proposed by Medley in his attempt to study the engineering properties of these geological mixtures and was defined as “a mixture of rocks, composed of geotechnical significant blocks within a bonded matrix of finer texture” [2].

Related to this problem, several approaches are important. For example, there are several methodologies present in the literature for estimation of the physical and the mechanical properties through empirical equations in practice [3-6]. An approach for engineering characterization of bimrocks in NW Greece is discussed by Nikolaidis and Saroglou [7]. Some elements that are important for this article are based on analyses of shear strength of different materials [8], or the approach for quantification of Geological Strength Index [9].

Having in mind the complexity of the problem, this paper aims to discuss some possibilities for evaluation of the properties of bimrocks, and for this purpose, one case study is presented.
2. Some data about the analysed area and methodology of work

2.1. Analysed area

The area of analysis is related to the SE part of Macedonia, i.e. the region from the cities of Shtip to Radovish, where an expressway with a length of about 30 km is in the final phase of construction.

Within a cut at km 23+200 - km 23+400 constructed in a volcanogenic rock of andesite type, some zones have typical elements of bimrocks, which will be discussed in this paper. The cut itself has an impressive height with maximal values of about 80 meters, constructed with berms at every 20 meters height with an inclination more than 60° [10].

These andesites have been created in two main phases under complex genetic-geological conditions with the existence of fault structures and joints that have served as supply channels for hydrothermal influences that decompose the rock. Primarily extruded andesites, later are tectonically affected, so in the frame of the rock mass, several types of andesites can be divided as quasi-homogeneous units. Sometimes, the “borders” between the quasi-homogeneous zones are sharp from one type to another or alternate between certain joint systems, which significantly complicates the geological composition of the terrain of the micro-location. Along wider faults, the alterations are also present, but the appearance of typical “core block” is visible as well. It can be underlined that, until the start of the excavation, it was very difficult to estimate the extent of each zone.

When it comes to the presence of bimrocks for the analyzed cut it can be noted that, some zones are connected with a weathering process where mixtures of decomposed soil surrounding fresher core-stones are present, similar to known cases from the practice (figure 1).

Other varieties of bimrocks relate to fault rocks, composed of blocks within gouge and sheared rock, usually with sharp “borders” with jointed andesites. (figure 2).

Figure 1. Core-stones in a cut section from 23+200 to 23+400 from decomposed andesite surrounded by matrix of grus - like material (up) and decomposed granite contains core-stones surrounded by a matrix of dense sandy soil (down, from Medley [11])
Figure 2. A view on the wall of the cut located within a major fault zone with sheared rock mass with blocks in a range of between centimeters and decimeters in size (left part of the picture) and jointed, andesite’s (right part of the picture).

For better visualization, these two zones were properly digitized (figure 3).

Figure 3. Digitized versions of the major fault zone with sheared rock mass with blocks in a range of between centimeters and decimeters in size with approximate area of about 8 m² or 2m height and 4 meters’ length (upper picture) and jointed andesite’s approximate area of about 18 m² or 3 meters’ height and 6 meters’ length (lower picture).

2.2. Methodology applied
The applied methodology for rock mass characterization is similar to the one explained by Nikolaidis and Saroglou [7] and modified to the scale of interest.

- Analyses of existing documents;
- Detailed engineering geological mapping, including simple field rock mechanics;
- Borehole drilling;
- Laboratory test on rock samples;
- Definition of relevant geotechnical parameters for main zones in rock mass;
- Defining of Factor of Safety (FS) and Probability of Failure (PF);
- Rockfall simulations
- Definition of Design solution

Based on these steps, in the analyses, special attention is given to the delineation of separate quasi-homogeneous zones within the rock mass, and that is explained in some elements in the frame of this article.
3. Bimrock and Rock Mass Characterization Parameters

3.1. Physical and mechanical properties of blocks and matrix

First, the parameters of intact parts were analyzed, using results from testing of Uniaxial Compressive Strength (UCS), Unit weight (γ), Point Load Strength (Js-50), and Schmidt Hammer Rebound Value (SHRV). Some correlations between main intact rock mass parameters are presented in figure 4 and figure 5.

![Figure 4. Unit weight (γ) vs UCS and SHRV](image)

![Figure 5. Unit weight (γ) vs Js (50)](image)

An attempt to define the differences between the parameters of the core blocks and the matrix was made. In general, four main classes of andesitic rock may be divided. Namely, two typical varieties of jointed fresh and altered andesites and two types of bimrocks connected with fault zones or weathering processes of the rock mass are present. For these classes, some data for the minimal and the maximal values within a range are used to define the Strength Ratio or the ratio between the values for blocks (b) and matrix (m). The results are given in table 1.

| Case | UCSb/UCSm | yb/ym | SHRvb/SHRvm | Js(50)b/Js50(m) |
|------|------------|-------|-------------|-----------------|
| 1    | 112/23=4.86 | 25.38/22.1=1.14 | 45/12=3.75 | 8/0.44=18.18   |
| 2    | 87/23=3.78  | 25/22.1=1.13  | 36/12=3    | 6.49/0.44=14.75 |
| 3    | 42/23=1.82  | 24.14/22.1=1.09 | 16/12=1.33 | 1.60/0.44=3.63  |
| 4    | 31/23=1.34  | 23.74/22.1=1.07 | 15/12=1.25 | 0.72/0.44=1.63  |

Case 1 in Table 1 refers to the zones of jointed andesites (fresh andesites), Case 2 is for slightly weathered and jointed andesites, Case 3 is for bimrocks in weathered zones and Case 4 is for bimrocks in fault zones. The typical values for each case are divided with the minimal values, which usually refer to the matrix. Based on these values, the ratio between the parameters is defined. The comparison of this ratio with the values for some indices that are usually used for the determination of the possible deterioration and the degree of weathering, presented with the formulas below, seems interesting.
\[ V_r = \frac{G_h - G_o}{G_h - G_a} \]  \hspace{1cm} (1)

where \( V_r \) is the degree of weathering by Zolotarev [12], \( G_h \) is the value of a chosen parameter for fresh rock, \( G_o \) is the value of the analyzed zone and \( G_a \) is the value for altered rock.

\[ R_s = \left( \frac{\sigma_c(\text{weathered})}{\sigma_c(\text{fresh})} \right) \times 100 \% \]  \hspace{1cm} (2)

where \( R_s \) is the strength ratio according to Gupta [13], \( \sigma_c \) is the value of compressive strength for weathered or fresh intact rock samples.

### Table 2. Data for weathering (alteration) parameters using different methods.

| Zone in rock mass                              | \( \sigma_c, \text{UCS} \) (MPa) | \( V_r \) (Case for UCS) | Rs (%) | UCSb/UCSm |
|-----------------------------------------------|----------------------------------|--------------------------|--------|-----------|
| Fresh andesite                                | 112                              | 0                        | 100    | 4.86      |
| Slightly altered andesite                     | 87                               | 0.28                      | 77.6   | 3.78      |
| BIM Rock in weathered zones                   | 42                               | 0.79                      | 37.5   | 1.82      |
| BIM Rocks In Fault zone                       | 23                               | 1                         | 20.5   | 1.34      |

In Zolotarev’s original classification [12], the values \( V_r = 0.9 – 1 \) are for highly weathered (altered) rocks, \( V_r = 0.7 – 0.9 \) for weathered rock, \( V_r = 0.3 – 0.7 \) for moderately weathered rocks, and \( V_r = 0 – 0.3 \) for slightly weathered rocks. In Gupta’s methodology [13], the values for \( R_s = 80 – 100 \) are for fresh rocks, \( R_s = 50 – 80 \) for slightly weathered, \( R_s = 25 – 50 \) for moderately weathered, \( R_s = 10 – 25 \) for highly weathered, and \( R_s < 10 \) for completely weathered rock. The correlation between the selected parameters is obvious (figure 6).

![Figure 6. Correlation UCSb/UCSm=f(Rs) – left and UCSb/UCSm=f(Vr) – right](image)

### 3.2 Applied methodology for determination of Volumetric Block Proportion and Rock Mass Parameters

The approach in the determination of Volumetric Block Proportion (VBP) is based on a visual separation of zones in the frame of the rock mass, on measurements along typical scanlines, and image analyses. The suggestions by Medley [2] that the scale of analyzed area for the definition of the distribution and sizes of blocks should be related to “characteristic engineering dimension”, and that the blocks would range between 5 and 70 % of that scale, are also taken into consideration. Compared with the scale of an open outcrop that ranges of about 20 m height between berms, the maximal values of the core blocks are in the range of 1,5 meters, the minimal values are about 5 cm, while mean values are between 0,3 to 0,5 meters (figure 7).
Figure 7. A view of core blocks with metric dimensions in the frame of the matrix as “obstacles” during the installation of slope protective measures.

In the estimation of volumetric block proportions at the field scale, the methodology of image analyses was applied in a similar manner as presented by Sonmez et al. [6]. For this purpose, the image data is classified by aggregating it into several spectral groups. The colored photographs are used and processed in several shades (figure 8).

Figure 8. Original and classified views of andesitic bimrocks in the frame of fault zone

A cross-check of grayscale and colored photographs indicates that it is possible to obtain relatively precise volumetric block proportion in different zones, and the results are used in the further development of a system for classification of bimrocks.

3.3 Introducing a concept of Block in Matrix Strength Index (BIMSI)
As a part of the analyses in the frame of the article, an attempt to introduce a concept for the classification of bimrocks using some quantitative parameters was made. The approach given by Hoek et al. [9] in the quantification of Geological Strength Index (GSI) was the initial idea, where two simple linear scales, VPB and Strength Ratio are used to represent the main parameters that determine bimrocks' behavior.

The ratings are calculated from the measured percentage of Volumetric Block Proportion using the ratio VBP/2. For the Strength Ratio of Unconfined Compressive Strength of blocks (UCSb) and matrix (UCSm), the ratings are given arbitrarily for some values of ratio from 1 to 0 (figure 9).
For example, if we have a case when UCSb=100 MPa, and UCSm=100 MPa, the ratio is 1 and for this case, the rating is 50. This is a theoretical case for an intact rock mass. For a case when UCSb/UCSm=2, the rating is 25, etc. Based on this approach, the first attempt of the preparation of BIMSI classification is presented in Figure 10.

On the diagram, the values of BIMSI>80 represent the rock mass with blocky structure, while the values of BIMSI<20 are for soil-like mixtures. We can note that the values of BIMSI are not a direct substitution of GSI values, but for a range of blocky rocks and soil-like mixtures, GSI can be used as adequate substitutes in the prognosis of shear strength and deformability of rock mass.

However, this can be treated as a first attempt to define this system, especially the influence of the block/matrix strength contrasts for two or more mechanically diverse blocks, and further work is underway to develop these analyses.

4. Lessons learned and conclusions
In the traditional geotechnical design practice, there are several approaches to define the characteristic of bimrocks, but this is a field that still has scope for further development. For the reasons stated in the article, it is important to note that the geological interpretation of materials in terms of their geological past is very important in assessing the mechanical properties of rocks, and therefore geology as science is of great importance in geotechnics [14]. According to the analysis in the paper, it follows that there are many challenges connected to the stability of the cuts made in bimrocks prone to degradation. It is clear, that the presented approach in this study should not be used for design purposes alone, and it needs further development. Some additional methods such as field tests should be considered for providing
safety of engineering projects constructed in/on bimrocks. It is noted that in this case, the slope protection is done by the system presented partially in Figure 7, and it is composed of support of self-drilling anchors with length from 3 to 9 meters at a distance from 2 to 3 meters, combined with three types of meshes: composite of hexagonal wire mesh and 3D polymer mesh, above which steel mesh is installed [10]. The details for the applied analytical and numerical methods for stability calculations overcomes the frame of this article.

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