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Effect of large blocks position on stability analysis of block-in-matrix slopes

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Abstract

Bimrocks are complex geomaterials that are defined as mixtures of rocks composed of geotechnically significant blocks within a matrix of finer texture. Bimslopes are made from bimrocks and are usually seen in weathered and shallow environments. Some characteristics of blocks affecting the strength of bimrocks include VBP (Volumetric Block Proportion), orientation, and arrangement, which have important roles in the stability of bimslopes. Previous studies show that bimrocks usually have a specific block size distribution, and for a bimslope with height of "H", the size of blocks is changed from 0.05H to 0.75H. In this paper, the influence of large blocks position on bimslope stability was investigated by the physical and numerical models. The blocks that had a dimension larger than 0.5H were considered as "large blocks". In this work, first, thirty physical models were created and tested using a titling table machine. These models have a specific block size distribution and VBP with ellipsoidal blocks. The main variable of the models is large blocks position, where three categories including lower part of bimslope, upper part of bimslope, and sporadic state are considered. Based on the results of physical trials, thirty numerical models at the laboratory scale were generated using the finite element method. After comparing the physical and numerical models, which showed a good accordance, the numerical models were developed to the natural scale. The theoretical bimslopes investigated in this work showed that the position of large blocks had a significant influence on the stability of bimslopes.

1. Introduction

Bimrocks (Block-in-matrix rocks) have been defined as "a mixture of rocks composed of geotechnically significant blocks within a bonded matrix of finer texture" [1]. The expression "geotechnically significant blocks" means that blocks and matrix contrast between their mechanical properties (such as elastic modulus, shear strength, friction angle, and cohesion) at the scale of engineering interest. The definition of bimrock comprises a wide range of geomaterials, which have distinct structures consisting of mixtures of weak matrix and stronger blocks: melanges, breccias, sheared serpentinites, fault zone rocks, lahar deposits, and volcanic agglomerates. The term "bimsoil" is also used for complex mixtures that include rock blocks surrounded by soil-like matrix such as weathered rocks (like decomposed granites), debris flows, colluvium, glacial tills, and mine waste disposal dumps [2-5]. An outcrop of bimrocks is shown in Figure 1.

The stability of slopes is considered crucial to public safety in highways passing through excavations and road cuts as well as to the personnel and equipment safety in open-pit mines. Slope instability and failures occur because of several already well-understood natural factors such as adverse slope geometries, geological discontinuities, and weak or weathered slope materials as well as severe weather conditions

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[6-8]. Different approaches such as empirical methods, kinematic analysis, limit equilibrium methods, statistical approaches, numerical modelling, and physical modelling are utilized for slope stability evaluation [9-14]. Empirical methods are usually employed for the preliminary assessment of the stability condition of the rock slopes and their engineering behaviours [6, 9]. Kinematic analysis is usually utilized to predict the potential of structural failures (planar, wedge, and toppling) using the stereonet projection approach [8]. The limit equilibrium methods estimate the safety factor of slopes according to comparing the magnitudes of the driving and resisting forces that act along the sliding planes [15-17]. Numerical modeling is often applied to more complex slope problems [7, 18]. Physical modeling is a powerful technique used to investigate the geotechnical problems such as slope stability analysis [12, 19].

Different engineering structures such as tunnels and slopes may be constructed in/on these mixtures of rock and soil. Several studies have been conducted on the aspects of stability analysis of bimrock slopes (or bimslopes) [18, 20-26]. However, due to the extreme natural complexity of bimrocks, more comprehensive studies are still required to further understand their characteristics and behaviour. Stability assessment of bimslopes, compared to the other slopes, is further complicated by uncertain factors such as inherent spatial variability of soil or rock properties and simplifications in the analysis procedure. With regard to these complexities, the researchers could not propose any mathematical model to analyze the stability of bimslopes. However, several statistical approaches have been developed to take these uncertainties into account in the performance of slope stability analysis [11, 14, 16, 27-29]. An investigation on the bimslope stability by limit equilibrium analysis has shown that the increase in safety factor is not only determined by the higher friction angle but also by the different paths of the potential slip surface negotiating around the blocks, especially the larger ones [20]. Hence, large blocks may have a significant role in the stability of bimslopes.

In this work, the influence of large blocks position on the stability of bimslopes was investigated. This factor has not been considered in the previous studies on the behaviour of bimslopes. For this purpose, the numerical and physical approaches were utilized. The numerical models of bimslope were developed using the Finite Element Method (FEM) by Phase^2 8.0. Besides, the physical models were made in a custom-manufactured apparatus. In this way, three different categories for the position of large blocks were defined, as discussed in the following sections. The results of both the numerical and physical models showed that the position of large blocks had a significant effect on the stability of bimslopes. Therefore, by considering this parameter in the phases of site investigation and design of bimslopes, more reliable results could be achieved.

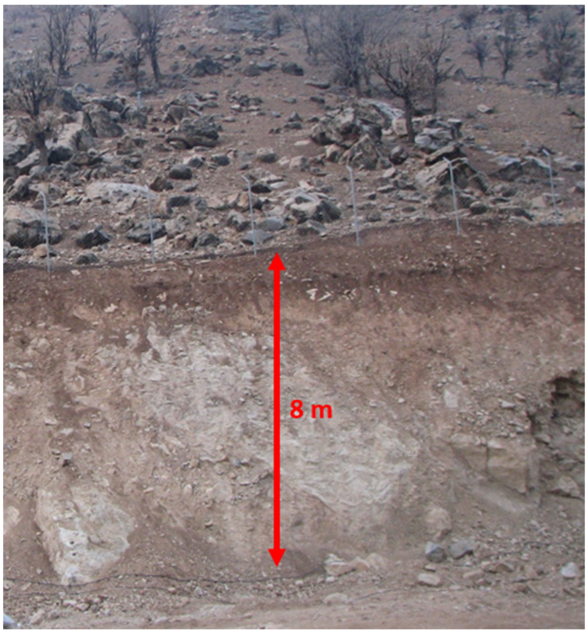


Figure 1. An outcrop of bimrocks, Khersan 3 dam site in Iran.

2. A brief review on characteristics of bimrocks

Many research works have been carried out on bimrocks to characterize these complex formations [25, 30-35]. According to the previous studies, VBP is one of the most important factors involved in the characterization of bimrocks [2, 36-39]. VBP is the total volume of blocks divided by the total volume of the studied mixture. Many studies have shown that this parameter has a significant effect on the strength of bimrocks [2, 30, 37, 40]. In addition, the overall mechanical properties of bimrocks are affected by the mechanical properties of the matrix and blocks, block size distributions, block shapes, orientation of the blocks, strengths of the block/matrix contacts, etc. [36, 41, 42]. When VBP increases in the range of about 0.25-0.75, the overall mechanical properties of bimrocks including Young's modulus and friction angle augment due the development of failure surfaces tortuously negotiating around blocks. Therefore, where there are weak block-matrix contacts, the overall cohesion of a bimrock mass may decrease because of the overall accumulation of the interfaces [2, 36, 39, 40, 43]. For VBP values less than about 25%, the mechanical properties of bimrocks are generally considered equivalent to those of the matrix. Above VBP values of about 75%, blocks tend to develop “contact to contact” geometry, and so the rock mass should not be treated as a bimrock but rather as “blocky rock mass with infilled joints” [1, 36, 44].

The block size distributions tend to be fractal (negative power-law) and scale-independent in many kinds of bimrocks such as melanges [44-47]. The size threshold between blocks and matrix is considered to be equal to $0.05L_C$, where L_C is a characteristic engineering dimension that clarifies the scale of engineering interest. With regard to the kind of geotechnical engineering problem, L_c can be defined such as slope height, tunnel diameter, laboratory specimen diameter, and footing width [1]. The block size distribution of one kind of bimrocks (Franciscan melange) is presented in Figure 2. In this figure, “A” is the area of desired scope ($L_C = \sqrt{A}$). The components with the dimensions smaller than $0.05\sqrt{A}$ are considered as matrix. The horizontal axis in Figure 2 is a normalized parameter: the ratio of maximum observed dimension (d_{mod}) of blocks to $\sqrt{A}$. Moreover, mechanical contrast between blocks and matrix, which is an initial condition for the mass to be classified as bimrock, is typically defined by strength ratio or stiffness ratio. Some criteria of mechanical strength between blocks and matrix in bimrocks are presented in Table 1.

In the current work, VBP of numerical and physical bimslopes was equal to 40%. Moreover, the block size distribution presented in Figure 2 was applied to create the theoretical bimslope models.

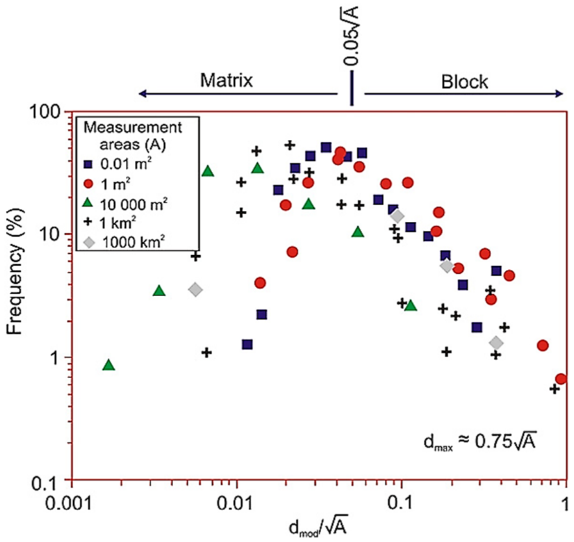


Figure 2. Normalized block size distribution of Franciscan melange to identify scale independence [After 1].

Table 1. Strength and stiffness contrasts between blocks and matrix in bimrocks.

Criterion	References
$(UCS_{blocks}/UCS_{matrix}) > 1.5$	[44]
$(E_{blocks}/E_{matrix}) > 2$	[36]
$(\tan\phi_{blocks}/\tan\phi_{matrix}) > 1.5\text{-}2$	[1, 30, 37, 40]

3. Physical modeling

3.1. Fabrication of physical models

In this work, the approach of tilt table test was utilized to evaluate the stability of physical bimslopes at the laboratory scale [48, 49]. For this purpose, the physical trials were performed by the "slope stability modeling apparatus", illustrated in Figure 3, which was custom-manufactured in the Rock Mechanics Laboratory of the University of Tehran. Several studies on the slope stability issues have been carried out using this apparatus such as a study on toppling failures [19]. This apparatus works by using electricity power, and has a box with dimensions of 100 cm × 50 cm × 70 cm, which is rotated around an axis. The rotation speed is very low and about 1 degree per minute to avoid the unwanted dynamic effects [50]. The physical model is made in the box, and by turning on the electrical motor, the model is rotated and it will be failed at the critical angle of bimslope face. This critical angle is equal to the initial angle of slope face at the horizontal condition of box, which is 60 degrees in all physical models, plus the table angle at failure moment. In other words, the failure angle is the maximum face angle of each physical bimslope in a stable condition. Besides, the height of all physical bimslopes has been 30 cm.

In this research work, a classification was proposed for the position of large blocks located within the bimslopes. For a bimslope with a height of H, the blocks that had a dimension larger than half of bimslope height (0.5H) were defined as "large blocks". Three different categories were considered for the position of large blocks:

I) Upper part: the large blocks are located in the upper part of bimslope (above 0.5H).

II) Lower part: the large blocks are located in the lower part (below 0.5H).

III) Sporadic: the large blocks are located randomly.

Regarding the random configuration of blocks in nature, 10 different arrangements of blocks were applied for each of the three categories. The artificial blocks were employed, which were constructed by cement (20%), plaster (40%), and water (40%) in ellipsoidal molds. As seen in Figure 4, these ellipsoidal blocks were made in four different sizes with the largest diameters of 4 cm, 8 cm, 14 cm, and 20 cm, and the ratio of large to short diameters of all blocks was set equal to the Golden Ratio (1.618).

The matrix used in this work was a mixture of sand and petrolatum. In order to prepare a suitable matrix for the physical bimslopes, Firuzkooh sand (No. 161) was utilized, which was a uniformly graded sand. Much research work has been conducted about the geotechnical problems and physical modeling using the same sand [51-53]. In order to add some cohesion, 1.5% petrolatum (or Vaseline) was mixed with this sand using an electric mixer so that a homogeneous mixture was obtained. The petrolatum used in this research work had a density of 0.9 g/cm^3 and a melting point of 41 °C. This mixture of sand and petrolatum had a unit weight of 1.12 g/cm^3. Given the fact that the petrolatum is somewhat sensitive to temperature variations, all models were done at an approximately constant temperature (23 to 25 °C). The sand-petrolatum mixture was compacted in all physical models so that a matrix with a unit weight of 1.3 g/cm^3 was achieved.

It was attempted to create a homogeneous and isotropic matrix around the blocks. However, some degree of vertical heterogeneity was almost imparted in the experiments since each layer of medium was compacted *in situ* resulting in an increased compaction of progressively lower layers. In other words, a load was applied to them when they were first compacted and when each overlying layer was compacted. Given that the mentioned heterogeneity occurred in a systematic way, its effect was ignored.

Table 2 presents the physical and mechanical characteristics of the matrix, blocks, and block/matrix interfaces. Most of the parameters presented in Table 2 were determined using the necessary laboratory tests. Direct shear tests were performed to assess the shear strength parameters of the matrix and also the interfaces between the matrix and blocks. For determining the shear strength parameters of interface, a cubic block was placed against the surface of a matrix volume in the box of a direct shear test. To specify the deformability parameters of the matrix including the Elasticity modulus and Poisson ratio, similar research works have been carried out on Firuzkooh sand (No. 161) and back analysis on the numerical models of matrix-only slope [54, 55]. The strength characteristics of the blocks were extracted from a research work that included a complete laboratory study on the same material that was here used to construct the blocks [56]. Figure 5 demonstrates the construction stages of two physical models. By performing trials, the failure angle of each physical bimslope was determined.

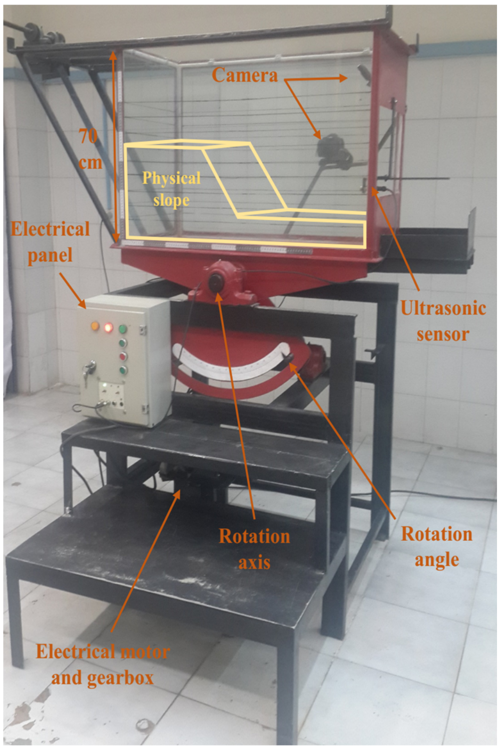
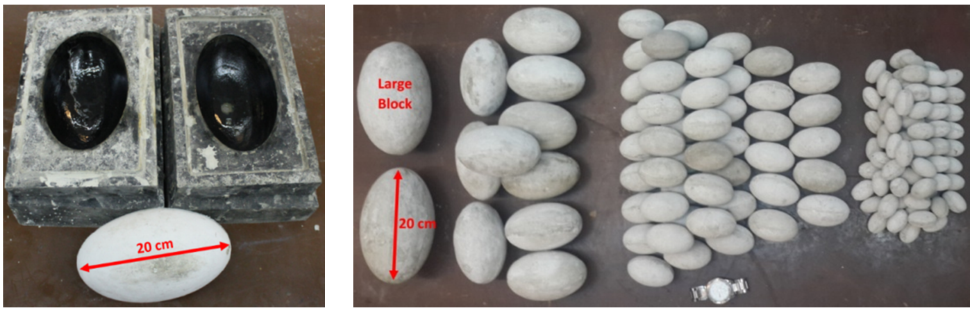


Figure 3. Slope stability modeling apparatus used in this work.

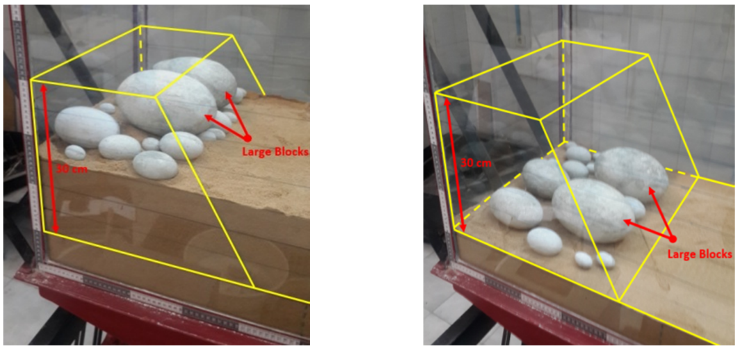


(a) **(b)**

Figure 4. Artificial blocks used in the physical models: (a) ellipsoidal mold and (b) different sizes distribution.

Table 2. Properties of the materials used in the physical bimslopes.

Parameter	Magnitude		
	Matrix	Blocks	Interface
Unit Weight (ton/m^3)	1.3	1.2	-
Cohesion (kPa)	1.7	9750	0.8
Friction angle (°)	17	24	14
Poisson ratio	0.3	0.2	-
Elasticity modulus (MPa)	15	10000	-



(a) **(b)**

Figure 5. Physical bimslopes for investigation into the large blocks position: (a) Upper part, and (b) Lower part.

3.2. Findings from physical models

At first, the failure angle of the matrix-only slope (without the presence of any blocks) was determined to be equal to 73 degrees. By comparing the failure angles of bimslopes with this value, it is possible to recognize the effect of each layout of large blocks position on the stability of bimslopes rather than matrix-only state. Figure 6 shows one of the physical bimslopes before and after performing the trial. It can be seen that the mechanical contrast between the blocks and surrounding matrix leads to force failure surfaces to negotiate tortuously around the blocks.

The statistical parameters of failure angles for various physical models are presented in Table 3. The mean values for the lower part position are more than the other two categories. Moreover, the box plots of measured failure angles are illustrated in Figure 7, which contains minimum (bottom of lower bar), first quartile (Q_1), median (Q_2), third quartile (Q_3), and maximum (top of upper bar) of data for each layout of large blocks. Q_1 is defined as the middle number between the minimum value and the median of the dataset, Q_2 is the median of the data, and Q_3 is the middle number between the median and the maximum value of the dataset. Therefore, 50% of data are located between Q_1 and Q_3. As shown, the failure angle for each category of large blocks position varies in a range, due to the different arrangements of blocks. The maximum variation range belongs to the sporadic layout. In other words, uncertainty in the results of sporadic layout is more than the other two ones. The presence of large blocks in the lower part increases the failure angle compared to the matrix-only state (73 degrees), while the failure angle can be decreased in two other categories.

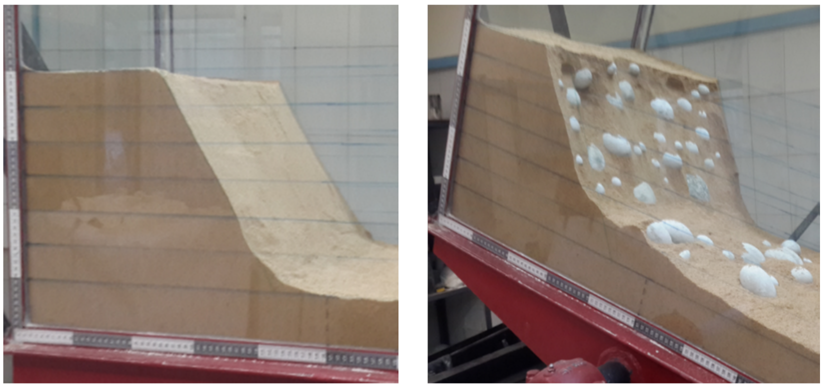

(a) (b)

Figure 6. Physical bimslope: (a) Before trial, and (b) After trial.

Table 3. Statistical parameters of failure angle for different positions of large blocks.

Parameter	Failure angle (degrees)		
	Upper part	Lower part	Sporadic
Minimum	71.50	75.00	70.00
Maximum	77.50	80.50	80.00
Mean	74.50	78.25	75.25

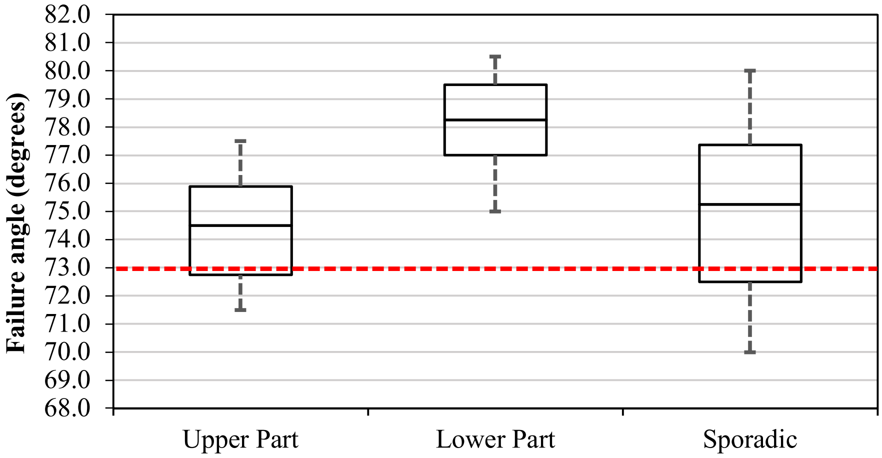


Figure 7. Box plot of failure angle for various positions of large blocks and the failure angle of matrix-only state (red dashed horizontal line, 73 degrees).

4. Numerical modeling on laboratory scale

4.1. Development of numerical models based on physical trials

As mentioned earlier, FEM by Phase^2 8.0 is used to model the behavior of bimslopes. To have a sensible comparison between the results of the physical and numerical models, efforts were made to ensure that most conditions of the physical models were built into the numerical models. The height and face angle of numerical bimslopes were considered 30 cm and 60 degrees, respectively. Moreover, the properties of the materials used in numerical models were the same as described in the previous sections and Table 2, and the shape of blocks was ellipsoidal and the ratio of larger dimension to smaller was equal to the Golden Ratio. Similar to the physical models, three categories for the position of large blocks were considered for the numerical bimslopes. Also for each category, ten different block arrangements were modeled. Furthermore, the factors VBP (40%) and blocks size distribution (the same presented in Figure 2) were considered constant in all models, although the blocks were arranged randomly in the body of both the numerical bimslopes and the physical models. Figure 8 presents one of the upper part numerical models of bimslope. This figure also shows the upper and lower parts, large blocks, meshes, and boundary conditions.

Three noded triangles with fine sizes were utilized to mesh the numerical models. The general geometry and boundary conditions as well as the finite element mesh built for one of the numerical models are shown in Figure 8. Based on the sensitivity analysis, the Mohr-Coulomb criterion was selected for the mechanical behaviour of the materials, which is the most common model in the context of geomaterials. Interfaces between the blocks and matrix were modeled as joint in the software.

To have a reasonable comparison between the physical and numerical models, before solving the finite element models, they were tilted to the mean values of the failure angles of the equivalent physical models. As mentioned in the previous sections, each physical model failed at a critical face angle. However, for a given layout of a large blocks position, each arrangement of randomly paced blocks led to a slightly different failure angle. Hence, there was a range of critical face angles for the same layout. By solving the numerical models, their safety factors (SFs) were calculated. In many numerical softwares such as Phase2 8.0, the critical strength reduction factor (SRF) was considered as SF.

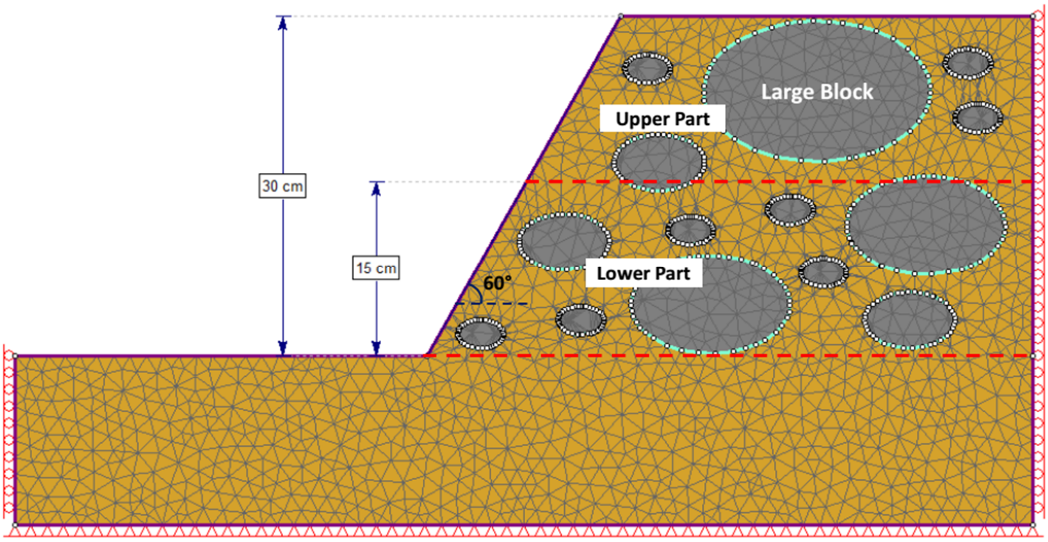


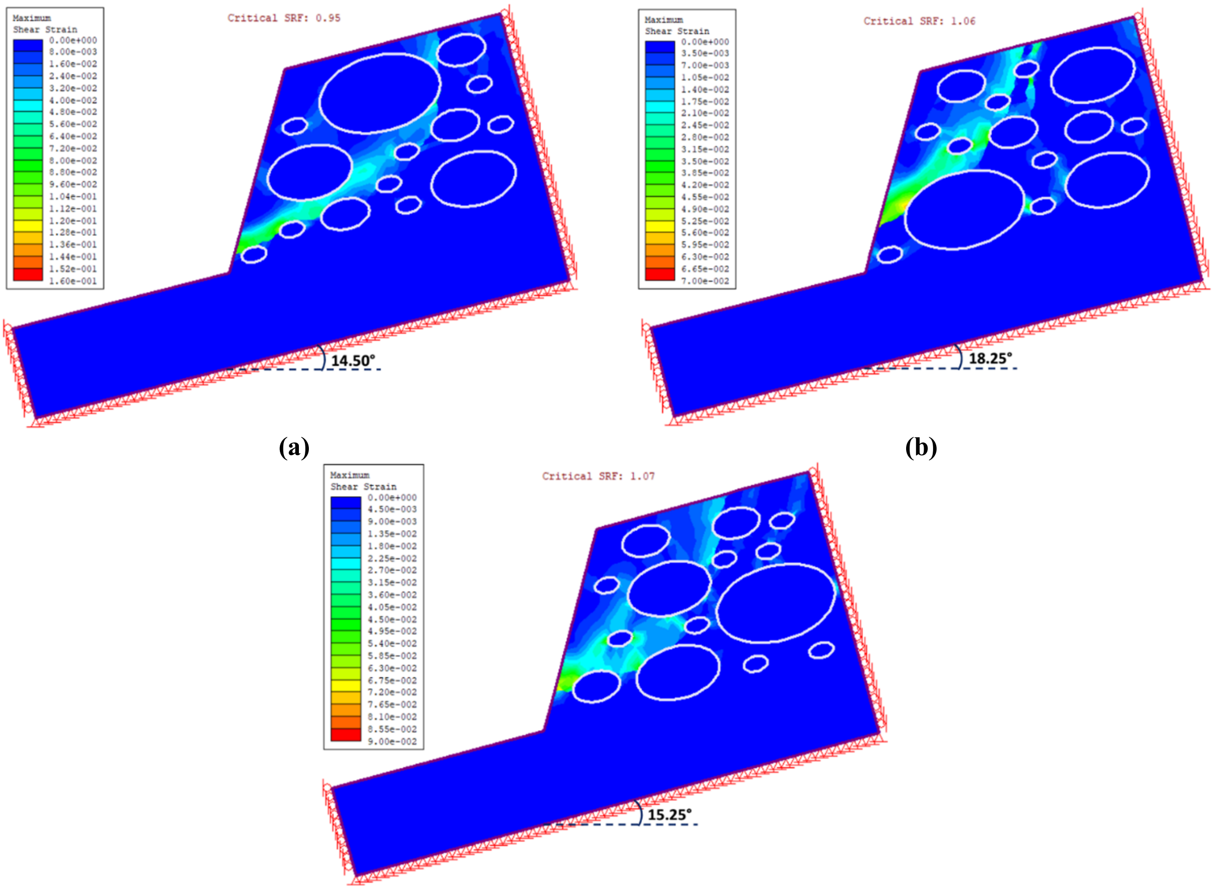
Figure 8. A numerical model of bimslope on laboratory scale, illustrating upper and lower part (an upper part example).

4.2. Findings from numerical models on laboratory scale

The numerical models were solved at the mean tilt angles obtained from the physical models, in which the failure of bimslopes had occurred. Figure 9 demonstrates the maximum shear strain in three different numerical models as well as the related rotation angles. As seen, the failure surface is formed through the matrix negotiating around blocks. Due to the presence of blocks, the slip surface is not circular, and it is significantly affected by the position of the blocks, especially the larger ones.

The safety factor values of numerical bimslopes were expected to be around 1 (the threshold between sable and unstable conditions) since the numerical models were rotated until mean values of failure angles achieved the physical trials. Figure 10 shows the box plots of safety factors related to each layout of large blocks position. It can be seen that the calculated safety factors with a difference of about 10% are located around 1. It shows that the numerical models are in good accordance with the physical models.

After generating acceptable numerical models on laboratory scale based on physical trials, it is possible to develop the numerical models on natural scale, which is presented in the next section.



(a) **(b)**

(c)

Figure 9. Maximum shear strain in some numerical models illustrating the rotation angles on laboratory scale: (a) Upper part, (b) Lower part, and (c) Sporadic.

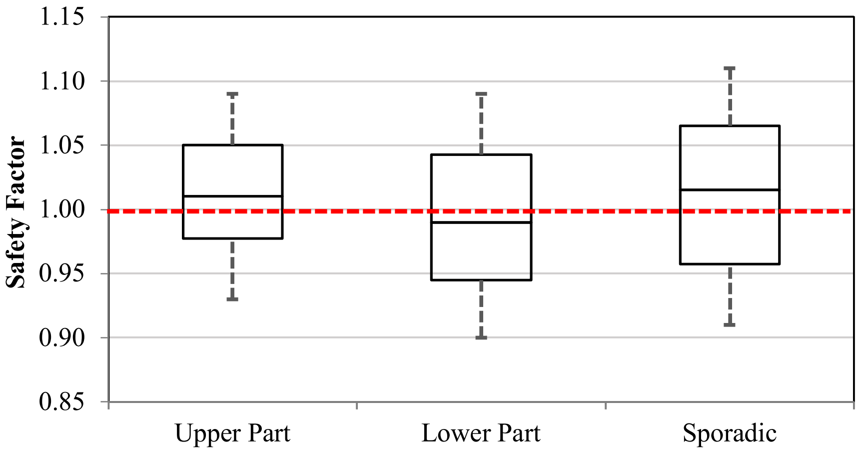


Figure 10. Box plot of NSF for various positions of large blocks.

5. Numerical modeling on natural scale

5.1. Development in scale of numerical models

To evaluate the effect of large blocks position on stability of natural bimrocks, 10 different configurations with various orientations of blocks were considered for each one of the three intended layouts (see Figure 11). The main variable in all these 30 models is the arrangement of blocks. The height and face angle of natural numerical bimslopes were considered as 10 m and 45 degrees, respectively. The properties of matrix, blocks, and interface of matrix and blocks used in these numerical models are shown in Table 4, which were considered according to the required contrast between the properties of matrix based on Table 1, and blocks and the common bimrocks available in the literature [25, 30].

Similar to the previous numerical models, SF is utilized as the stability criterion of bimslopes on natural scale. To generalize the results, SF of bimslopes was normalized by the SF value for the matrix-only state (0.88). Hence, Normalized Safety Factor (NSF) is defined as Eq. (1):

$$NSF = \frac{SF_{Bimslope}}{SF_{matrix}} \tag{1}$$

where $SF_{Bimslope}$ and SF_{Matrix} are the safety factor of bimslope and the matrix-only state, respectively. Therefore, using NSF, the results obtained will be more general and can be used in other similar cases.

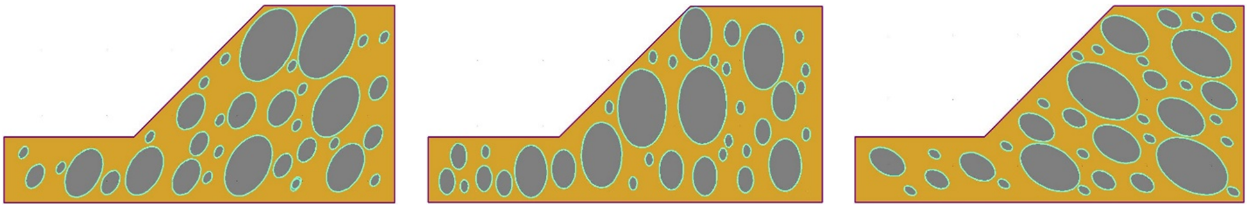

(a) (b) (c)

Figure 11. Three examples of block configuration within the numerical bimslopes on natural scale with various orientations of blocks: (a) Upper part, (b) Lower part, and (c) Sporadic.

Table 4. Properties of the materials used in the natural numerical bimslopes.

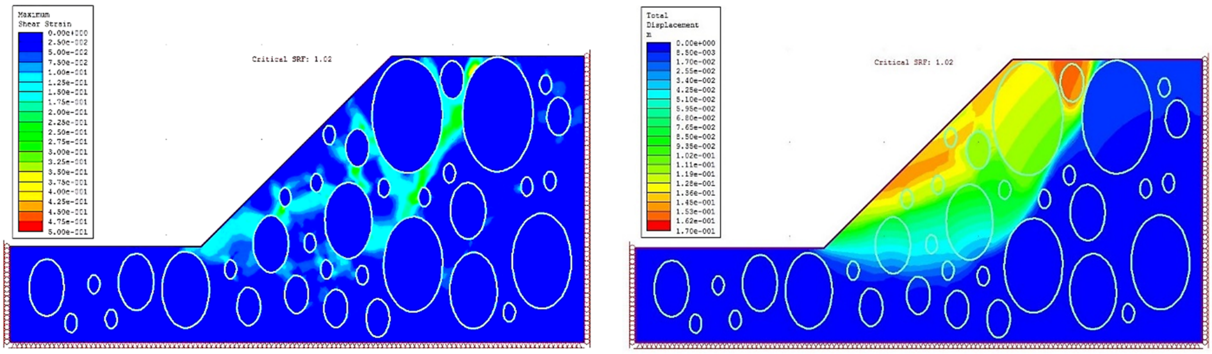
Parameter	Value		
	Matrix	Blocks	Interface
Unit Weight (ton/m^3)	1.8	2.3	-
Cohesion (kPa)	10	1000	8
Friction angle (°)	25	35	14
Poisson ratio	0.25	0.25	-
Elasticity modulus (MPa)	30	100	-

5.2. Findings from numerical models on natural scale

The results of one of the upper part numerical models are shown in Figure 12. As expected and can be seen in Figure 12 (a), like the laboratory scale models, the failure surface negotiates tortuously around the blocks. Moreover, Figure 12 (b) demonstrates the distribution of total displacement within this example of natural bimslope.

Table 5 presents the statistical parameters of NSF for various numerical models. Based on the results obtained, the mean NSF of the lower part is more than the upper part and sporadic categories. The presence of blocks in the lower part (near toe) increases SF of bimslope by about 28% rather than the matrix-only slope, while it is about 12% and 16% for the upper part and sporadic categories, respectively.

The box plots of NSFs obtained are illustrated in Figure 13. As shown, the maximum and minimum variation ranges of NSFs belong to the sporadic and upper part layouts. The presence of large blocks in the lower part has the most positive effect on the stability of bimslopes. In the categories of upper part and sporadic, SF of bimslopes may be decreased rather than matrix-only slope. In bimslopes with the properties similar to these numerical models, it is possible to have an estimation of SF for each layout of large blocks position (for bimslopes with VBP of 40%) using the values obtained for NSF and based on SF of the matrix-only slope. For instance, if SF of the matrix-only state of a bimslope with large blocks located in the upper part is 1.05, then with regard to the values of NSF, SF of this bimslope may vary between 1.04 and 1.31. This range of SF is due to the various possible arrangements of blocks within the bimslope.



(a) (b)

Figure 12. One of the upper part numerical models on natural scale: (a) Maximum shear strain, and (b) Total displacement.

Table 5. Statistical parameters of NSF for different positions of large blocks.

Parameter	Upper part	Lower part	Sporadic
Minimum	0.99	1.08	0.95
Maximum	1.25	1.48	1.44
Mean	1.12	1.28	1.16

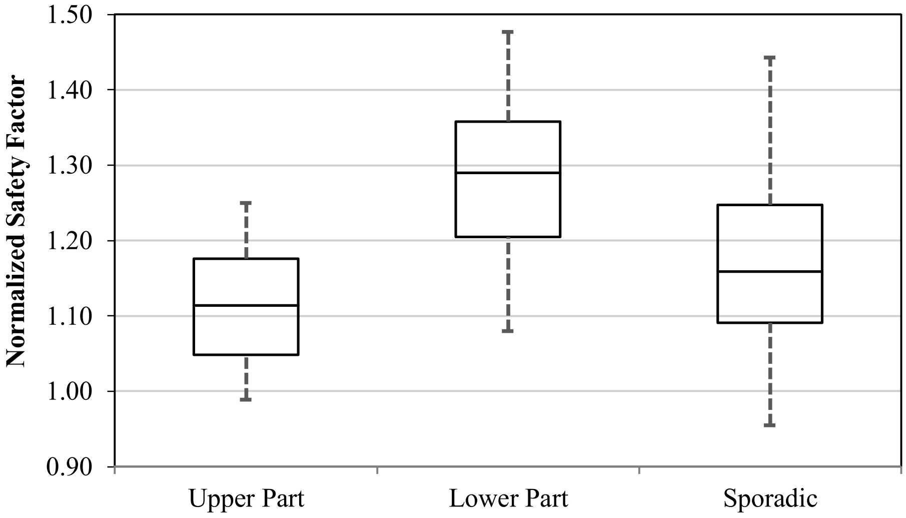


Figure 13. Box plot of NSF for different positions of large blocks.

6. Results and discussion

In the previous sections, the effect of large blocks position on stability of bimslopes was investigated by the physical and numerical modelings. After creating the numerical models on the laboratory scale based on the specifications of the physical models, several numerical models were developed on a much larger scale to investigate the behaviour of natural bimslopes. Important remarks and outcomes of the models are presented and discussed in the following.

Regarding the observed behaviour of the physical bimslopes during the trials, the numerical models were created as 2D. However, 3D numerical models may lead to different and more consistent results.

According to the literature of bimrocks, the mechanical contrast between the blocks and matrix was considered for all models in both the laboratory and natural scales (see Table 1, Table **2** and Table **4**). Slip surfaces in all models negotiated tortuously around the blocks. Therefore, the position of blocks has a significant influence on the propagation path of the slip surface. In this regard, the position of large blocks has a more effect on the stability condition of bimslopes.

In the physical models tested by the slope stability modeling apparatus, the maximum stable angle of face (failure angle) was considered as the stability criterion of bimslope, whereas the Safety Factor (SF) was used in the numerical models. To generalize the results obtained from the numerical bimslopes on natural scale, the Normalized Safety

Factor (NSF) was employed, which is a dimensionless parameter based on SF of matrix-only state of the desired bimslope. Based on the values of NSF, the presence of blocks causes to increase the stability of bimslope rather than matrix-only slope. The maximum increase in safety factor is related to the lower part category with a magnitude of about 50%. By examining the mean values of NSF, it can be realized that the presence of large blocks in the lower part has a more positive effect on the stability condition of bimslope. Moreover, when the large blocks are located in the upper part, the least increase in the SF occurs. As expected, a random configuration of large blocks (sporadic category) leads to the most variation range of NSF. It is because of the considerable role of the large blocks position on the stability of bimslopes, where various possible positions of large blocks cause a wide range of NSF. Generally, both the numerical and physical approaches emphasize that the presence of large blocks and their positions have noticeable influences on the stability of bimslopes.

7. Conclusions

In this research work, the effects of large blocks position on the stability of bimrock slopes (bimslopes) were studied. For this purpose, the physical modeling approach was employed by the slope stability modeling apparatus. In addition, the numerical modeling technique was used by the finite element method (Phase^2 8.0). The numerical models were first created on a laboratory scale and based on the specifications of the physical bimslopes, and then developed on a real scale and with the specifications of natural bimrocks. In all models, the common block size distribution of bimrocks and VBP of 40% was applied. The main variables in all the physical and numerical models were the arrangement of blocks and especially large blocks position.

Although the 2D finite element method was used in this work, due to the many discontinuities in this kind of geomaterial, the application of a distinct element method such as the particle flow code (PFC) may yield more reliable results. Therefore, the use of more appropriate numerical methods is recommended for future studies on the behaviour of bimslopes.

The results of the physical and numerical models were in good agreement and showed that the position of large blocks had an important role in the stability of bimslopes. The presence of blocks in the lower part of a bimslope leads to an increase in the stability, which is similar to the effect of retaining walls in trenches and slopes. Hence, it is very important to consider the position of large blocks in the procedure of stability analysis. The main outcomes of this research work can be summarized as follow:

- The position of large blocks in a bimslope has a significant effect on its stability.
- The presence of blocks in the lower part of bimslope has a more positive influence on the safety factor and stability rather than the other states.
- When the blocks are located in the upper part or randomly, the stability of bimslope may be decreased rather than the matrix-only slope.
- According to the results of the numerical models on natural scale, it is possible to estimate the safety factor of bimslopes with VBP of 40%. At first, SF of matrix-only slope should be calculated. Then with regard to the position of large blocks, a coefficient (NSF) can be extracted from the results to achieve the safety factor of bimslope. In a conservative manner, the least magnitude of NSF may be selected.

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تأثیر موقعیت بلوک‌های بزرگ بر تحلیل پایداری شیروانی‌های مخلوط سنگی

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چکیده:

مواد مخلوط سنگی یا بیم‌راک‌ها مواد پیچیده زمین‌شناسی هستند که به عنوان یک ترکیب سنگی، شامل بلوک‌های قابل‌توجه ژئوتکنیکی درون یک ماتریس متصل شده با بافت ریزتر تعریف می‌شوند. شیروانی مخلوط سنگی از این مواد تشکیل می‌شود و معمولاً در محیط‌های هوازده و کم‌عمق مشاهده می‌شود. برخی مشخصات بلوک‌ها که بر مقاومت مواد مخلوط سنگی تأثیر می‌گذارد شامل نسبت بلوک حجمی، جهت یافتگی و آرایش آن‌ها است که نقش مهمی بر پایداری شیروانی‌های مخلوط سنگی دارند. مطالعات گذشته نشان می‌دهد که ابعاد بلوک‌های موجود در مواد مخلوط سنگی معمولاً از یک توزیع مشخص پیروی می‌کند و برای یک شیروانی به ارتفاع H، ابعاد بلوک‌ها از ۰/۰۵H تا ۰/۷۵H تغییر می‌کند. در این پژوهش، تأثیر موقعیت بلوک‌های بزرگ بر پایداری شیروانی‌های مخلوط سنگی با استفاده از مدل‌های عددی و فیزیکی مورد بررسی قرار گرفته است. بلوک‌هایی که ابعادی بزرگ‌تر از نصف ارتفاع شیروانی (۰/۵H) دارند به عنوان بلوک بزرگ لحاظ شده است. در این پژوهش، در ابتدا ۳۰ مدل فیزیکی ایجاد شد و با استفاده از یک ماشین میز شیب‌دار مورد آزمایش قرار گرفت. این مدل‌ها توزیع ابعاد بلوک مشخص و نسبت بلوک حجمی معین با بلوک‌های بیضوی داشته‌اند. متغیر اصلی در این مدل‌ها، موقعیت بلوک‌های بزرگ بوده است که شامل سه دسته بخش پایین شیروانی، بخش بالای شیروانی و وضعیت تصادفی است. بر اساس نتایج آزمایش‌های انجام شده بر روی مدل‌های فیزیکی، ۳۰ مدل عددی در مقیاس آزمایشگاهی با استفاده از روش اجزای محدود تولید شد. پس از مقایسه مدل‌های فیزیکی و عددی که تطابق خوبی نیز داشتند، مدل‌های عددی به مقیاس طبیعی توسعه داده شد. شیروانی‌های مخلوط سنگی تئوری که در این پژوهش بررسی شدند، نشان دادند که موقعیت بلوک‌های بزرگ اثر قابل‌توجهی بر پایداری این شیروانی‌ها دارد.

کلمات کلیدی: مواد مخلوط سنگی (بیم‌راک)، شیروانی مخلوط سنگی، بلوک‌های بزرگ، مدل‌سازی عددی، مدل‌سازی فیزیکی.
