A Study on Dynamic Shear Properties of Bimrock

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ABSTRACT: Dynamic shear strength of rocks is of critical importance for rock mechanics and rock engineering applications. In this study, dynamic direct shear tests were carried out to investigate the dynamic shear strength of welded weak bimrocks and to determine the effect of volumetric block proportion (VBP) on dynamic shear behavior. For this purpose, artificial model bimrock specimens with different VBP were constituted, due to challenges in extracting undisturbed natural specimens. According to the results, most of the model specimens show strain hardening behavior after the dynamic shear failure occurs. The dynamic shear strength of specimens increases with the increase in the VBP values. In addition, the VBP of the shear failure surfaces at the end of the tests are obtained through digital image processing analyses. It is concluded that the VBP values of failure surfaces have an effect on the shear strength parameters as well as the overall VBP.

Keywords: Bimrock, Dynamic Shear Strength, Dynamic Shear Test, Volumetric Block Proportion.

1 INTRODUCTION

The mixtures of rocks that are composed of geotechnically significant blocks within a bonded matrix of finer texture is defined as bimrocks by Medley (1994) and Medley and Lindquist (1995). There must be a certain strength contrast between the constituents to define a soil rock mixture as bimrock. The engineering properties of welded bimrocks under static loading conditions is elaborately studied by some researchers. Most of the previous studies on bimrock pointed out that there are difficulties in conducting in-situ and laboratory tests and extracting samples due to the constituents of different rock types with variable strengths and sizes causing heterogeneous nature of them (Medley 1994; Lindquist 1994; Sönmez et al. 2006a; Kahraman et al. 2008; Avşar 2020; Coli et al. 2011; Li et al. 2004; Xu et al. 2007; Zhang et al. 2016). On the other hand, studies on the geo-engineering behavior of bimrocks under dynamic loading conditions are very limited (Lin et al. 2019).

This study aims to investigate the effect of volumetric block proportion (VBP) on dynamic shear strength parameters and shear behavior of welded bimrocks. In this context, artificial cubical samples having different VBP (20%, 40%, 55%) and the same block size distribution were prepared. The mesoscale direct shear tests under dynamic loading conditions were conducted to reveal the dynamic shear strength parameters of bimrocks. The results of this study will make a contribution to the selection of dynamic design parameters of low-strength welded bimrocks especially in seismically active regions.

2 PREPERATION OF ARTIFICIAL BIMROCK SAMPLES

Due to it is challenging to take undisturbed samples of bimrocks in line with the suggested methods and/or globally accepted standards, many researchers such as Linquist (1994), Sönmez et al. (2006b), Kalender et al. (2014), Afifipour and Moarefvand (2014), Mahdevari and Maarefvand (2018) preferred to use model samples in their studies. Artificial bimrock samples were used in this study to obtain samples with the planned volumetric block proportion ratio and to ensure homogeneity in sample sets. Medley (1994) suggested a threshold dimension between the blocks and the grains of the matrix considering a characteristic engineering dimension (Lc) which depends on the scale of engineering interest. In this study, artificial cubical samples with the dimensions of 15x15x15 cm were prepared and therefore the Lc would be 15 cm. The block/matrix threshold dmin is defined as 0.05*15=0.75 cm and the upper bound limit dmax is calculated as 0.75*15=11.25 cm. The largest block in the model bimrock samples is selected as 7 cm in diameter to avoid using blocks 11.25 cm in diameter is going to be too large for the artificial samples. ASTM suggests that to eliminate the impact of the scale effect and to obtain the minimum strength disregarding engineering dimensions, it is suggested that the diameter of core specimens to be at least ten times larger than the largest fragment's diameter. However, it is not practical to apply this requirement to bimrock and bimsoils. Furthermore, no recommended methods or standards have been proposed thus far for preparing specimens of such rock masses. Previous studies (e.g. Avşar, 2020; Coli et al., 2011; Kahraman et al.,2008; Kalender et al., 2014; Medley and Zekkos, 2011; Sönmez et al., 2006b; Sönmez et al., 2016, Xu et al., 2011) have commonly considered the characteristic engineering dimension when estimating the strength and deformation properties of block in matrix rocks, and this concept is widely acknowledged in the literature. The VBP mainly controls the overall strength of the bimrock in case of the VBP ranges between 20-25% and 75% VBP (Coli et al., 2011; Lindquist and Goodman, 1994; Lindquist, 1994). Since it is difficult to prepare artificial samples with VBP values higher than 50-60%, the VBP values of 40% and 55% was chosen as the intermediate and the highest, respectively. A total of 12 artificial samples were composed, 9 of which were bimrock samples with VBP values of 20%, 40%, 55% and 3 of which were matrix model samples consisting of matrix material without blocks. Fragmented tuff and granulated tuff were used in composing block and matrix components of model bimrock samples, respectively (Figure 1a). The average dry unit weight and the uniaxial compressive strength of the tuff are determined as 15.5 kN/m3 and 9.5 MPa, respectively. Accordingly, the uniaxial compression strength of the matrix is selected 2.2 MPa to provide the strength contrast between the components of the artificial samples. To prepare identical samples, the block size distribution of the block components is set to be the same in each sample. For this purpose, diameters of the block components 1.11, 1.91, 2.54, 3.81, 5.08, 6.30 and 7.00 cm were used in certain proportions corresponding to the same grain size distribution for different VBPs. A view of artificial cubical samples is presented in Figure 1b.

3 DYNAMIC DIRECT SHEAR TESTS

The artificial bimrock and matrix samples were subjected to dynamic direct shear tests using a direct shear testing apparatus. The loading part of the testing system has a closed-loop servo control shear device that contains two special rigid frames for vertical and shear forces, especially combined to prevent friction and torque. The maximum load capacity of the cyclic shear force is 500 kN, and the stiffness of the robust constructed frame is sufficiently high. GEOsys software is operated and controlled the whole test system (Wille Geotechnik, 2022).

(a) (b)

Figure 1. (a) Constituents of artificial bimrock samples, (b) artificial cubical bimrock samples drying at room temperature.

The artificial cubical bimrock samples were put in the shear boxes and fixed to the boxes with the help of adjusting screws so that their upper and lower surfaces were parallel to the horizontal plane. To completely prevent the sample's movement inside the box during shearing, a strong plaster with a strength of 36 MPa was poured into the gaps between the box and the sample (Figure 2a). The lower box and the sample was turned and put into the upper box after the plaster was hardened, and the fixing processes with screws and plaster were repeated as in the lower box. The sample within the shear box was placed in the direct shear test setup as seen in Figure 2b-c.

(a) (b) (c)

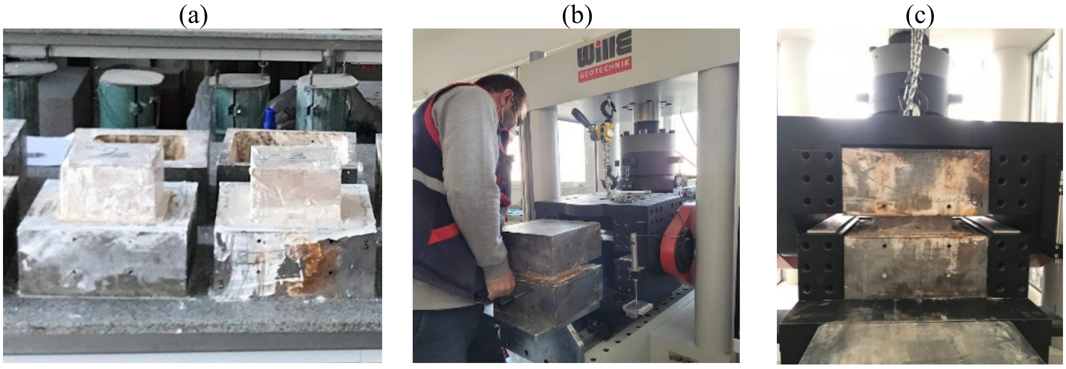


Figure 2. Stages of the dynamic shear tests test setup.

In this study, normalized "displacement-time" data consisting of displacements that are increasing and decreasing at a rate of 0.015 mm/sec is generated to ensure a regular displacement series considering that the displacement-time responses of the earthquake records have values that can instantaneously fluctuate with various amounts. The software sets the required level of movement by recalculating the displacement levels according to the maximum allowable deformation selected for the tests. In the trial tests, the artificial samples reached the maximum shear stress and then failed at a displacement of approximately 3 mm. Based on this, the allowable displacement was set up to 5 mm during all tests to also record the post-failure shear behavior of the samples. Additionally, the duration of dynamic loading is limited to 60 seconds.

4 RESULTS

The dynamic direct shear tests were performed for normal stresses of 250 kPa, 500 kPa and 750 kPa, and the shear stress (kPa) vs. shear displacement (mm) and shear stress (kN) vs. time (sec) responses for each artificial sample were plotted. Then, the shear stress (kPa) vs. normal stress (kPa) curves were obtained for each test set. A representative shear stress (kPa) vs. shear displacement (mm) graph showing hysteresis loops is given in Figure 3. In all tests, the shear failure and the post-failure stages were explicitly observed. The artificial bimrock samples failed at displacement values ranging between 0.36 mm and 3.73 mm and at 5.85 sec. and 37.64 secs. Both strain-hardening and strain-softening behaviors were observed from the shear stress (kPa) versus time (sec) responses of some of the tests. The shear stresses higher and lower than the shear failure stress were also determined after reaching the failure stress indicating both strain softening and strain hardening behaviours successively during the dynamic shear loading.

(a) (b) (c)

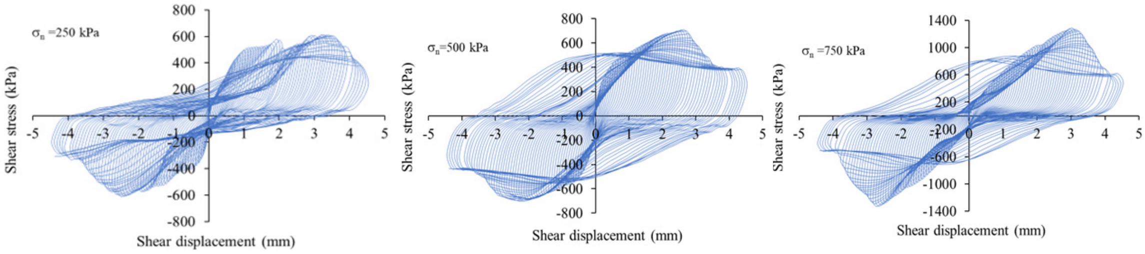


Figure 3. Dynamic shear stress vs shear displacement responses bimrock samples with VBP =55%.

The reason of both behaviours is observed successively may be the tortuosity of shear surfaces caused by blocks. Thus, the first reached maximum shear stress identified as the shear failure stress (τ_f) at which the shear failure of the model sample occurred. The shear failure envelopes of the samples having the VBP values of 20%, 40%, 55% were plotted (Figure 4). The dynamic shear strength parameters cohesion (c_{dyn}) and internal friction angle (ϕ_{dyn}) of artificial bimrock samples were determined from these failure envelopes (Table 1). The c_{dyn} of the samples ranges between 277 kPa and 305 kPa, and the ϕ_{dyn} changes between 36^0 and 42^0. Additionally, the c_{dyn} and the ϕ_{dyn} of the artificial matrix samples (VBP=0%) are 259 kPa and 25^0, respectively. The results indicated that the shear strength parameters c_{dyn} and ϕ_{dyn} increase as the VBP increases (Figure 5). The failure surfaces of the artificial samples were examined and the VBP of the failure surfaces ($VBPf_s$) were determined After performing the direct shear tests (Figure 6). The blocks on the failure surfaces were digitized using the digital image processing (DIP) analysis technique to calculate the VBP of them. The DIP analyses showed that the $VBPf_s$ values of failure surfaces vary between 22% and 53% with an average value of 38% and standard deviation of 7.4%.

5 DISCUSSION AND CONCLUSIONS

It is clearly seen from the failure envelopes (see Figure 4), the dynamic shear strength of the model samples increases with the increasing of VBP up to 55%. Even though the block content of samples with 40% VBP is twice that of samples with 20% VBP, the failure envelopes and thus the c_{dyn} and the ϕ_{dyn} values of the samples in these two groups are found to be close to each other. The main reason for that result is the VBP values of the failure surfaces (VBPfs) of the model bimrock samples in the two test sets are close to each other. It is concluded that the VBP of the model samples have substantial effects on the dynamic shear strength of bimrocks, but on the other hand, the VBPfs could also markedly influence the dynamic shear strength parameters. The increase in the ϕ_{dyn} with increasing VBP values can be attributed to the augmentation in roughness and/or tortuosity due to the increase in the proportion of blocks on the failure surface during shearing. Since the bimrock samples investigated in the previous studies have different block size distributions as the VBP values change. However, in this study, the quantitative definition of block size distribution is adjusted to same in samples that have different VBP to minimize the effect of block size distribution. The preparation of the model bimrock samples by changing only a single property (e.g. VBP) is one of the advantages of this study in terms of providing a single parameter to be examined.

Table 1. The dynamic shear strength parameters of matrix and artificial bimrock samples.

Test sets	VBP (%)	c (kPa)	ϕ (^{0})
Set 1	20	277	36
Set 2	40	302	37
Set 3	55	305	42
Matrix	0	259	25

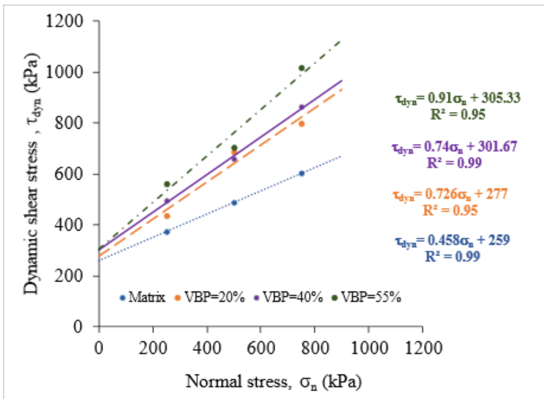
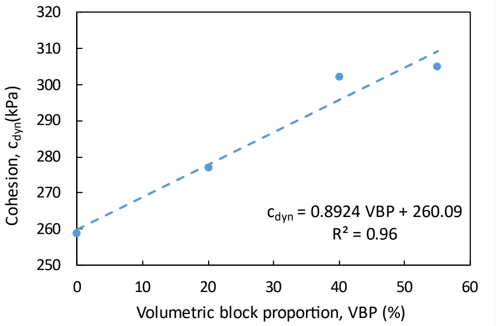


Figure 4. The shear failure envelopes of the samples having the VBP values of 0%, 20%, 40% and 55%

(a)



(b)

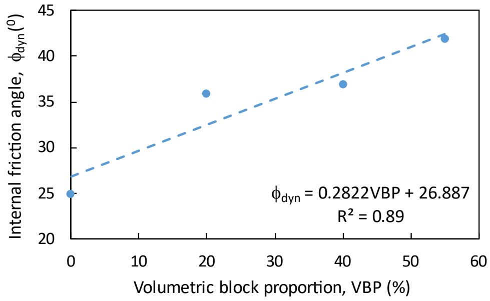


Figure 5. The relationships between (a) the VBP and the c_{dyn}, (b) the VBP and the ϕ_{dyn} of matrix and bimrock samples.

Figure 6. The failure surface and digitized image of sample no. 11 (VBP= 40%, VBPf$_s$ =42%).

The main conclusions obtained from this study can be drawn as follows:

- The dynamic shear strength of the model bimrock samples increased with the increase of the VBP values. Accordingly, the ϕ_{dyn} and c_{dyn} also increase due to the increase in VBP.
- Strain softening and mainly strain hardening behaviour were observed in most of the samples. In addition, in some of the tests both strain hardening and strain softening behaviours were successively developed probably due to the tortuosity caused by the blocks on the shear surfaces of the model bimrock samples.
- The c_{dyn} and ϕ_{dyn} of the test sets having 20% and 40% VBP values were determined to be close to each other. The reason of this result is associated to the close VBPfs of the failure surfaces of these samples. The highest dynamic shear stress was recorded in the test of the model sample having the highest VBPfs. These results mean that considering the

VBPfs of the samples together with the VBP may provide a more accurate evaluation of the dynamic shear strength of bimrocks and bimsoils.

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