Characterization of Bimrocks (Rock/Soil Mixtures) With Application to Slope Stability Problems

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ABSTRACT: Bimrocks, (block-in-matrix rocks) are mixtures of competent blocks of rock surrounded by weak matrix rocks, which are often sheared and soil-like. Bimrocks, such as chaotic melanges and fault rocks, are found worldwide in mountainous regions and are prone to slope instabilty problems. The overall mechanical properties of bimrocks are dominated by matrix strength, volumetric block proportion, block orientations, block shapes and block size distributions. These factors influence the tortuosity of failure surfaces which invariably pass around blocks. Despite the apparent chaos of many bimrocks, disciplined characterization for slope stability investigations can be performed. Preliminary analyses with simple geotechnical models of bimrocks and boulder-rich colluvium indicate that block volumetric proportion is an important factor in variations of the Factor of Safety for slope stability. The relationship appears to be valid despite marked differences in modelled geology, block size distributions and block orientations.

INTRODUCTION

Geological mixtures of competent blocks of rock encased in weaker matrix often frustrate designers, contractors and owners and result in construction claims (Button et al., in press). Medley (1994) introduced the term *bimrock* (block-in-matrix rock) for geological mixtures composed of geotechnically significant rock blocks within a bonded rock matrix of finer texture, where "geotechnical significance" means that there is a sufficient volume of blocks with mechanical contrast between blocks and matrix to force failure surfaces to negotiate around the blocks. Bimrocks include melanges, sheared serpentinites, breccias, decomposed granites, weathered rocks with corestones, and tectonically fragmented rocks such as fault rocks. The most intractable bimrocks are melanges (from French: *mélange*, or mixture), exemplified by those of the Franciscan Complex (Franciscan) of California, but they occur globally in mountainous terrains. Although melanges are common, only relatively recently have guidelines been presented for their characterization (Medley, 2001, Wakabayashi & Medley, in press), and aid is offered here in the characterization for the preliminary geotechnical analysis of melanges and other bimrocks for slope stability problems. Also introduced is a relationship between volumetric block proportions and Factor of Safety.

FACTORS INFLUENCING TORTUOSITY OF FAILURE SURFACES IN BIMROCKS

1.1 *Blocks, Matrix and Shears*

Clues to melanges are the presence of rocks of different lithologies juxtaposed in improbable fashion (Wakabayashi & Medley, in press) within a "scaly clay" matrix of intensely sheared shale (e.g. *argille scagliose* of Northern Italy). Blocks in Franciscan melanges are commonly greywacke, are roughly ellipsoid with minor:major axes of 1:2 and greater, and often have slickensided and polished surfaces. Well-fractured blocks may have little strength contrast with matrix and should then be considered matrix. As shown in Figure 1, melange rock masses can contain block-poor and block-rich regions. Blocks in Franciscan melanges are found at all scales of engineering interest and the range of block sizes extends more than 7 orders in magnitude, between sand and mountains (Medley and Lindquist, 1995). Medley (2001) suggested appropriate scaling dimensions be selected for the problem at hand (termed the "characteristic engineering dimension") such as the height of a landslide, the diameter of a tunnel, or the width of a foundation. At the selected scale of interest, blocks are limited to between about 5% and 70% of the characteristic engineering dimension. The materials below the 5% limit are matrix and those above 70% are blocky rock masses.

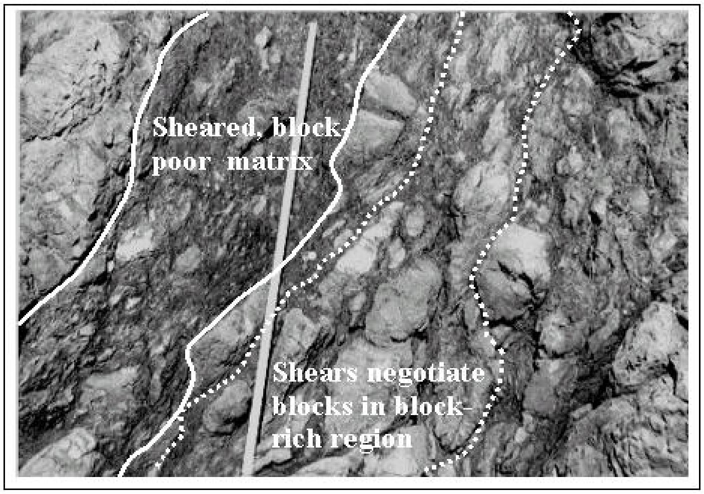

Figure 1. Franciscan melange showing anisotropic fabric of elongated blocks entrained within sheared shale matrix at Caspar Headlands, Mendocino County, California. Scale bar is 1.5m. Outcrop shows both block-poor, sheared matrix and block-rich regions with shear surfaces (dashed) negotiating blocks.

Matrix rocks in Franciscan melanges are most often fractured and broken to completely sheared soil siltstone and shale. Shears tortuously pass around blocks (Figure 1 and Figure 2), and may be denser around large blocks (Figure 1). Landslides are common in block-poor melanges, and large blocks buttress slopes.

1.2 *Effects of Volumetric Block Proportion, Block Shapes and Orientations on Tortuosity*

The overall mechanical properties of bimrocks are mainly affected by the mechanical properties of the matrix, the volumetric block proportion, the block shapes, the block size distributions and the orientation of the blocks relative to failure surfaces. When the block proportions are between about 25% and 70%, the increase in the overall mechanical properties of bimrocks are mainly and directly related to the volumetric block proportion of blocks in the rock mass (Lindquist and Goodman, 1994). The increase in the overall friction strength can be as much as 15 degrees to 20 degrees above the matrix friction strength because of the tortuosity of failure surfaces. Increases in volumetric block proportion also lead to a decrease in the bimrock cohesion. Irfan and Tang (1993) identified similar relationships between volumetric block proportion and shear strength for Hong Kong colluvium containing boulders to 7m in size. Measurements of block chord lengths from borings, and maximum observed dimensions of blocks from outcrop mapping, are used to estimate block volumetric proportions Medley (1994, 1997).

Lindquist & Goodman (1994) determined that bimrock strength was generally least when the general direction of the major axes of the blocks were oriented about 30 degrees (45^o-($\varphi_{matrix}/2$) degrees) relative to the direction of the maximum principal stress. From a slope stability viewpoint, it is thus vital to characterize the fabric of anisotropic bimrocks, such as fault rocks (Riedmueller et al., 2001) and melanges with sub-parallel blocks and shears (Figure 1). When blocks and surrounding shears are oriented out-of-slope, there is decreased slope stability (Figure 2A, 2D and 2D).

Conversely, blocks oriented at high angles to slopes increase stability (Figure 2C) due to increased tortuosity. Large blocks or block-rich regions at the toe of slopes tend to buttress slopes and add to slope stability (Kim, Snell & Medley, 2004). However, in melanges and fault rocks, the orientations of blocks and shear fabric vary throughout the rock mass, as smaller blocks entrained in shears swirl around larger blocks. Consequently, the orientation of failure surfaces will vary throughout the slope.

Block shapes influence the tortousity of failure surfaces most when coupled with the orientation of the blocks. Elliptical blocks have the greatest deleterious effect on slope stability when the direction of the major axes is co-incident with the direction of shearing (Figure 2B).

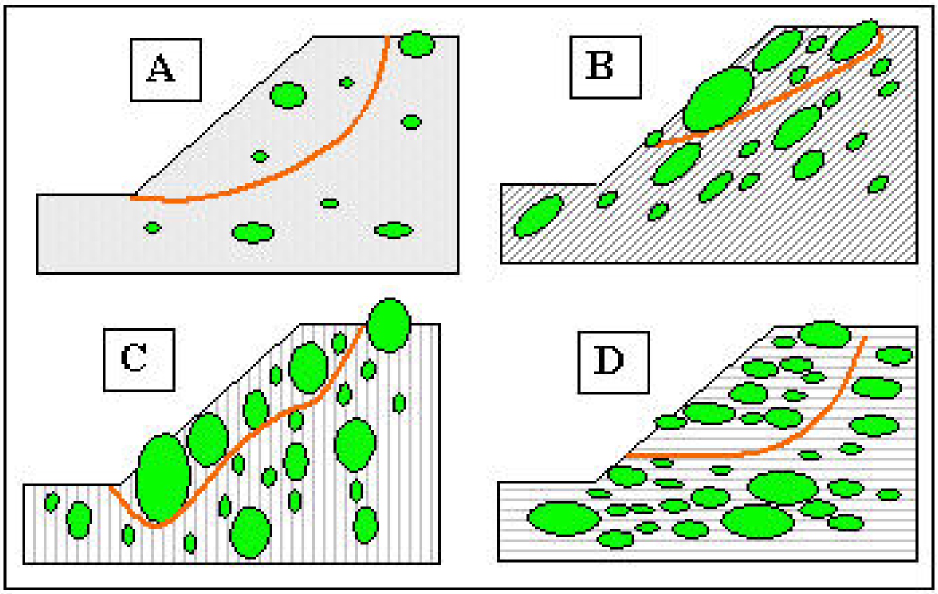

Figure 2. Some possible slope situations in bimrocks. A) low block proportion (block-poor) bimrock with critical failure surface unimpeded by blocks. B) anisotropic bimrock, such as melange, with blocks and shears oriented out of slope, and failure surface guided by the fabric. C) blocks and shears oriented vertically such that failure surface is tortuous and slope stability enhanced. D) regions of block-rich anisotropic bimrock interrupted by block-poor zone with failure surface; slope stability is reduced by heavy upper block-rich zone.

2 EFFECTS OF BLOCK PROPORTION ON SLOPE STABILTY

2.1 *Idealized Bimrock Model*

The presence of blocks increases the slope stability relative to the stability of the slope in pure matrix. To explore this effect, Medley & Sanz (2003) developed a simple model to investigate the slope stability of idealized bimrocks. As shown in Figure 3, the model slope was inclined at 35 degrees. The slope height of 10 m was the characteristic engineering dimension. Analyses were performed using horizontal rectangles with aspect ratios of 2:1 to model ellipsoidal Franciscan blocks, and using block size distributions typical of the Franciscan (Medley and Lindquist, 1995). Random block arrays of 50%, 25% and 13% areal block proportions of the model cross-sections (similar to Figure 3) were assumed to be equivalent to volumetric block proportions, although such an assumption is not generally valid for real bimrocks (Medley, 1997).

The strength parameters of the matrix were selected to be $c = 10$ kPa (200 pounds per square foot) and $\varphi = 25$ degrees, based on experience with Franciscan melanges. The strength of the blocks and the block/matrix contacts were neglected, and water table was considered to be below the area of study. Initially, a critical failure surface for a matrix-only slope was identified (dashed arc on Figure 3) with a

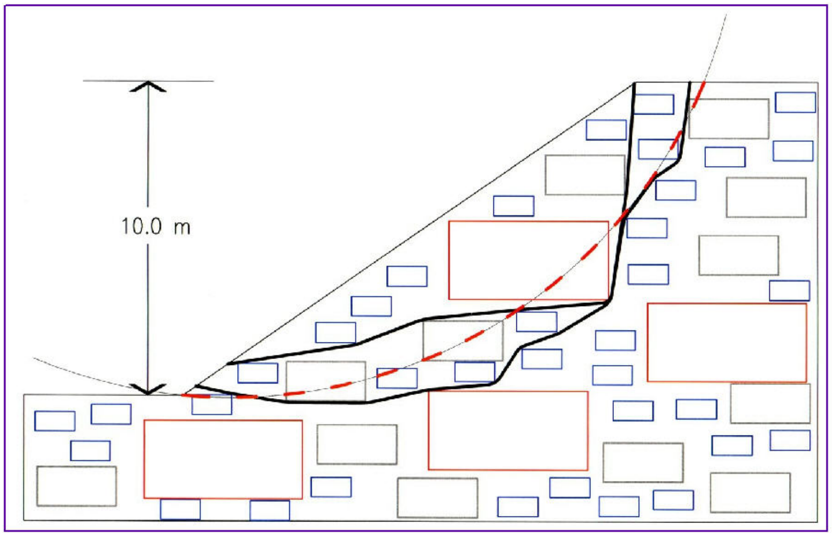

Figure 3. Example model bimrock with 50% areal block proportion and randomly distributed blocks. Dotted line is critical failure surface for matrix only; solid curved lines show two possible failure surfaces for the bimrock. (After Medley & Sanz, 2003).

Factor of Safety of 1.26. Using an engineering graphics program, the failure surface defined by this analysis was then used as a template in several bimrock models to identify possible failure surfaces negotiating around blocks. Graphical tracings of the possible failure surfaces were then exported into SlopeW™, (Geo-Slope International, Inc.) and the slope stability analyses performed to yield Factors of Safety. To generalize the findings, the Factors of Safety were normalized by dividing them by the Factor of Safety for the matrix-only case (FS=1.26).

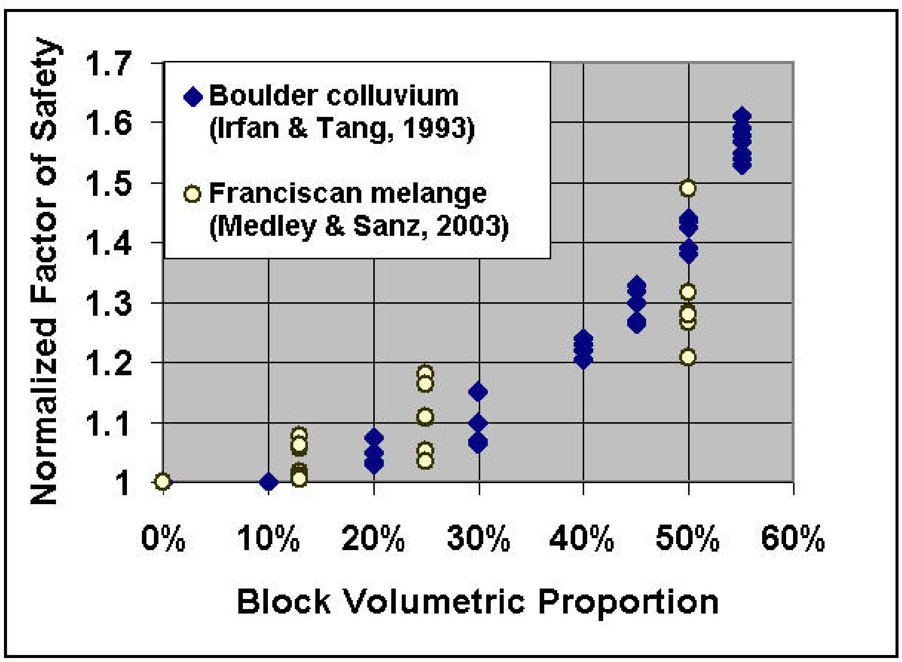

Figure 4. Comparison of results for models of geologically disparate rock/soil mixtures: Hong Kong boulder colluvium (Irfan & Tang (1993) and Franciscan melange (Medley & Sanz, 2003).

The results of the individual analyses are summarized in Figure 4, which shows a relationship between normalized Factor of Safety and volumetric block proportion. All other variables constant, the Factor of Safety depends on increases in the tortuous lengths of failure surfaces with increasing volumetric block proportion.

2.2 *Comparison with Results of Slope Stability Analyses of Coarse Colluvium*

As shown in Figure 4, the findings described above were compared to those of Irfan & Tang (1993), who performed stability analyses of theoretical slopes in bouldery soil, as part of a broader investigation into the shear strength of coarse colluvium in Hong Kong. The model slopes were 10m high and inclined about 60 degrees (Figure 5). Uniformly sized and uniformly separated blocks were layered out-of-slope. Block proportions were varied between 10% and 55%. The strength properties of the matrix were generally selected as c'= 5 kPa and φ' = 35 degrees. The Morgenstern & Price (1965) method of stability analysis was used on potential failure surfaces drawn block-to-block from the corners of adjacent blocks, resulting in zigzag failure surfaces with regular amplitudes (Figure 5).

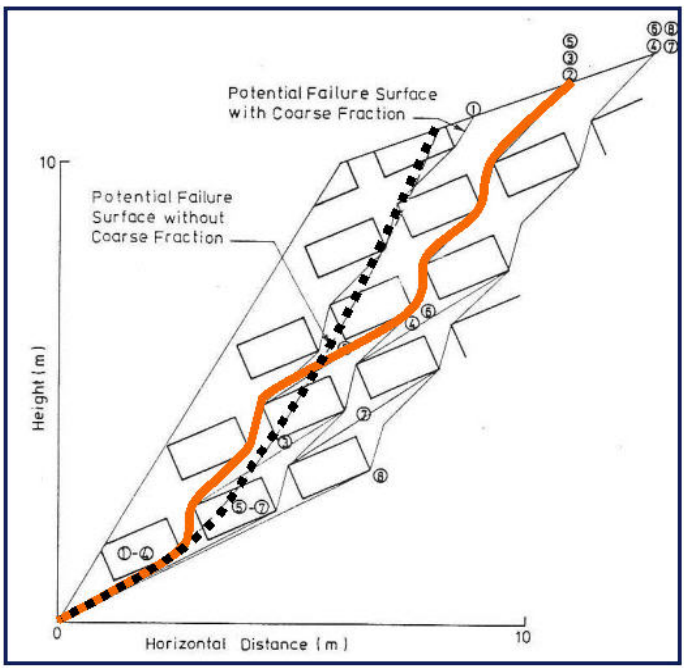

Figure 5. A 20% block proportion model of boulder colluvium. Dotted line is critical failure surface for matrix only. Solid line is a tortuous trial failure surface. (After Irfan & Tang, 1992).

Figure 4 compares the results of Medley & Sanz (2003) and Irfan & Tang (1993). There is a good relationship between the normalized Factors of Safety and the volumetric block proportions, despite the significant differences in the model geometries, orientation of blocks, geology of the modelled materials, and analytical methods used. Although considerably more analyses should be performed to define the statistical variations, it appears that up to about 25% to 30% block proportion, the presence of blocks provides relatively little geomechanical advantage. However, from this lower limit to greater than 55%, there is marked increase in slope stability. This finding is similar to that of Lindquist & Goodman (1994) who determined that there was as much as about 16 degrees of frictional strength advantage (relative to the frictional strength of the matrix) for physical model melanges with volumetric block proportions between about 25% and 70%.

Irfan & Tang (1993) determined that the layering of blocks was as important as the volumetric proportion itself. Blocks with their long directions oriented parallel to sliding yielded lower normalized Factors of Safety than blocks arrayed normal to the overall sliding direction, due to increases in the resulting tortuosities of failure surfaces around the blocks. They also determined that the relative increase of friction angle with increasing block proportion was far greater than the increase in cohesion.

3 CONCLUSIONS

The Factor of Safety for slope stability of bimrocks increases with the tortuosity of actual and potential failure surfaces. The increase is largely related to volumetric block proportions and block orientations. Block orientations (relative to directions of governing stresses) are controlled by anisotropies of block and shear fabrics. The finding that the Factor of Safety is related to volumetric block proportion is encouraging because commonly used analytical tools may then become useful to the practitioner investigating the slope stability of geologically complex mixtures such as melanges, fault rocks and other bimrocks. Nevertheless, more work must be performed, perhaps by performing Monte-Carlo type simulations using 3-Dimensional models, to understand the statistical viability of using simple analytical approaches for complex geological conditions.

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