PROCEEDINGS INTERNATIONAL SYMPOSIUM ON ENGINEERING GEOLOGY AND THE ENVIRONMENT, ORGANIZED BY THE GREEK NATIONAL GROUP OF IAEG / ATHENS / GREECE / 23-27 JUNE 1997

Engineering Geology and the Environment

Editors
P.G. MARINOS
National Technical University of Athens
G.C. KOUKIS
University of Patras
G.C. TSIAMBAOS
Central Public Works Laboratory, Athens
G.C. STOURNARAS
University of Athens

OFFPRINT / TIRE-A-PART

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1997

Engineering Geology and the Environment, Marinos, Koukis, Tsiambaos & Stournaras (eds)

Uncertainty in estimates of block volumetric proportions in melange bimrocks

Edmund Medley
Failure Analysis Associates, Inc., Menlo Park, Calif., USA

ABSTRACT: A study was performed using physical models to determine the uncertainties associated with estimates of block volumetric proportion. It was found that as the total sampling length and/or the actual volumetric proportion increased, the uncertainty decreased. In the case of a melange rock mass below a dam, incorporation of uncertainty lowered an initial estimate of block volumetric proportion of 40% to 32%, which turn justified the revision of strength parameters.

RÉSUMÉ: On a étudiê à l'aide de modèles physiques l'incertitude associée à l'évaluation de pourcentage volumétrique des blocs. Plus la longeur d'échantillonage et/ou le pourcentage volumétrique augmentent, plus cette incertitude diminue. Dans le cas d'une masse rocheuse de mélange située sous un barrage estimée initialement contenir 40% de bloc, la prise en compte de cette incertitude conduisit à reduire cette proportion à 32%. Cela entraîna une révision des propriétés mécaniques.

1 INTRODUCTION

A melange body (French: *mélange*) is a mixture of relatively strong blocks of rock, ranging in size between sand and mountains, embedded within a weaker matrix of sheared argillite, shale, siltstone or serpentinite. Melanges have been identified in the mountainous regions of over 70 countries (Medley, 1994a, 1994b) and are represented in northern California within the Franciscan Complex ("the Franciscan".) Melanges are part of the large family of block-in-matrix rocks that Medley (1994b) called *bimrocks*, which are mixtures of rocks composed of geotechnically significant blocks, within bonded matrices of finer texture.

The matrix rock of melanges is commonly pervasively sheared. Blocks in melanges tend to be ellipsoidal, and within the Franciscan are generally composed of graywacke, chert, greenstone and serpentinite (Medley, 1994a). Medley (1994b) and Medley and Lindquist (1995) showed that, the block size distributions of the several Franciscan melanges were scale-independent. In other words, the appearance of a melange is similar whatever the scale of interest. Medley and Lindquist (1995) provided a generalized relationship between any number blocks of any given size class is $2n^{2.3}$ (or approximately $5*n$) where n is the number of blocks in the next largest size, the relationship being a power law with a negative exponent. Furthermore, they showed that the length of the largest block (d_{max}) in any given area (A) of Franciscan melange is approximately $\sqrt{A}$ long; and the threshold between blocks and matrix is approximately equivalent to $0.05\sqrt{A}$ ($0.05d_{max}$.)

Melanges are geotechnically intractable because of their chaotic spatial variability and the weak, often soil-like matrix materials. The great mechanical contrast between blocks and matrix frustrates good core recoveries, reliable laboratory test results and accurate geotechnical characterizations. Conventionally, engineers design on the basis of the weak matrix, but Lindquist (1994a, 1994b) and Lindquist and Goodman (1994) showed that the mechanical properties of a melange are simply and directly related to the block volumetric proportion. But the use of these fundamentally powerful findings requires estimates of the block volumetric proportion, which Medley and Goodman (1994) proposed could be assumed to be stereologically equivalent to the cumulative linear proportion of blocks in the melange rock mass (the sum of the lengths of all blocks intersected by scanlines or drill core, divided by the total length of the core.).

However, to use this methodology in the case of design for a dam founded on Franciscan melange in northern California, it was necessary to determine the uncertainties in the design strength parameters. Consequently, the approach described here was devised.

2 DATA COLLECTION

2.1 *Fabrication of Physical Models*

Four physical bim (block-in-matrix) models were constructed with known block volumetric proportions of about 13%, 32%, 42% and 55%. The models were composed of Plaster of Paris matrices in which were embedded ellipsoidal blocks made of dried pottery clay and Play-Doh (children's modeling clay, a modern form of Plasticene). Models were fabricated with "plan" dimensions of 150 mm by 100 mm ($A=170\ cm^2$, $\sqrt{A} = 13$ cm) and depths of between 150 mm and 100 mm.

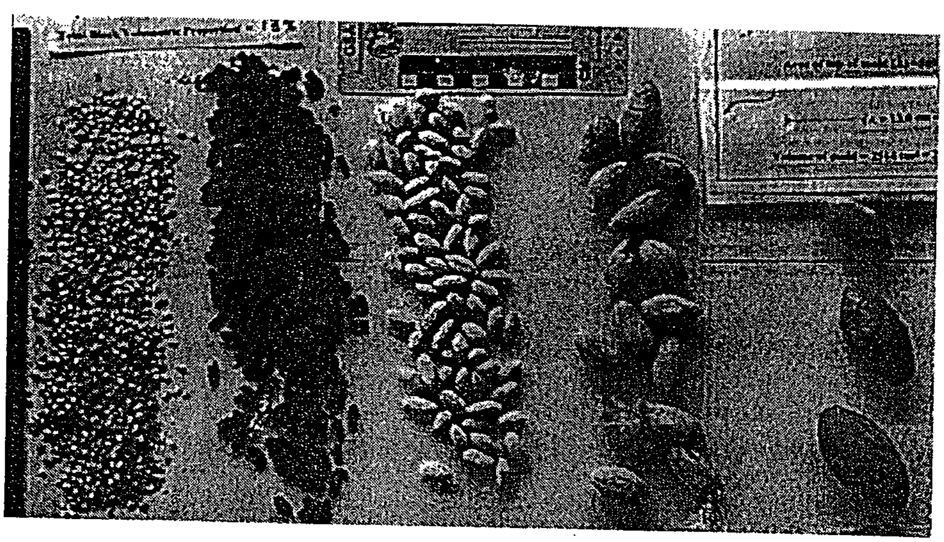

Figure 1 Blocks fabricated for the 13% bim model

The ellipsoid blocks were generally handmade from the clay and Play-Doh, with lengths of the major/intermediate/minor axes in the ratio 2:1:1. Rice was used for the smallest size class (3mm - 6mm), which was the block/matrix threshold $0.05d_{max}$. Additional size classes ($0.1d_{max}$ $0.2\ d_{max}$ $0.4\ d_{max}$ and $0.8\ d_{max}$; or 6mm - 12mm; 12mm - 24mm; 24mm - 48mm; and 48mm - 96mm) matched log-histogram endclass bins as described by Medley (1994b) and Medley and Lindquist (1995). The length of the largest blocks (d_{max})n the bim models were of the order of 70 to 95 mm. To fabricate the correct number of blocks required for each model, the block size distributions followed the "$2n^{2.3}$" fractal distribution described by Medley and Lindquist (1995), which was considered to be a typical block size distribution for Franciscan melanges. The total number of blocks required in the models ranged between 2200 (13% model) and 7300 (55% model), as exemplified by Figure 1.

The volumes of the blocks were determined by the water displacement method. Once all blocks were fabricated, Plaster of Paris was prepared, mixed with the smaller blocks and poured into the molds. The larger blocks were then hand-placed and oriented generally vertically into the plaster to model a Franciscan melange with typical steeply dipping blocks. (The blocks were not uniformly distributed throughout the models, which realistically simulates the chaotic distribution of blocks in real melange.) The models were cured for 24 hours and measured to determine the overall volume of the model and the block volumetric proportion. The "true" block volumetric proportion for each model was then calculate as the total of the volumes of the blocks divided by the total volume of the model.

2.2 *Measurement of Scanlines*

When cured, each model was sawn into 10 slices (Figure 2) each of which was photographed. Ten scanlines, (linear sampling traverses) were drawn across each photograph (Figure 3) to represent model boreholes through model vertical cross-sections. Thus, 100 model boreholes were defined for each bim model. The lengths of the intercepts between the scanlines and blocks were then measured only for those intercepts that were longer than about 6 mm ($0.05\sqrt{A}$) which is the scale-independent threshold length between blocks and matrix (Medley and Lindquist, 1995).

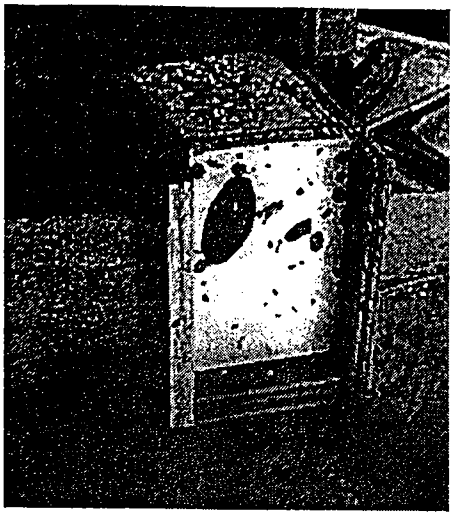

Figure 2: Sawing of 13% model into slices

The block linear proportion of each scanline was calculated by dividing the sum of the intercept lengths through each block traversed, by the total length of the scanline. Thus, each model yielded an evenly distributed array of 100 block linear proportions in plan view, as exemplified by a typical array shown in Figure 4. The example here clearly shows the considerable and unpredictable range in individual block linear proportions measured at each scanline. These spatially varying data lend themselves to geostatistical analysis, which is left to others to perform.

Despite the locally extreme variations in linear block proportions, if all 100 scanline data were used, the cumulative linear proportions of the bim models closely matched the "true" block volumetric proportions. In reality such detailed exploration would be unfeasible. Indeed, it is because such extravagant sampling cannot be economically performed that the research sought to determine the adjustments that would need to be made to estimates of block volumetric proportion collected from drilling programs with much shorter total lengths of coring.

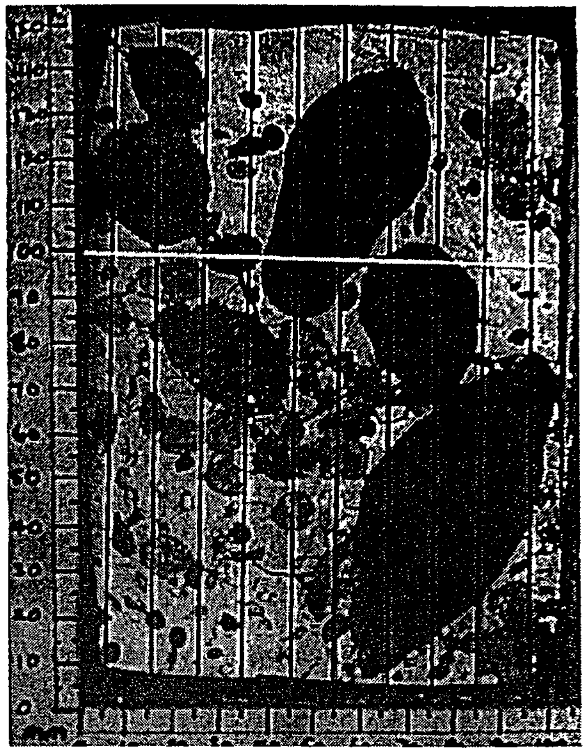

Figure 3: 42% bim model with a set of 10 superimposed vertical scanlines. White horizontal line marks bottom limit of "short" scanlines.

"Short" scanlines of about 1/3 of the depth of each model were also measured to simulate drilling into a rock mass to depths shallower than the full depth of interest.

The complete data set measured from the bim models was 800 linear proportions, being one set of 100 for long lines ("deep boreholes"), and a set of 100 for short lines ("shallow boreholes") for each of the 4 models.

34.7	25.9	6.3	0.0	27.0	13.3	22.5	26.8	31.1	41.7
40.0	33.3	44.0	29.6	18.5	39.7	42.5	25.3	19.1	40.3
31.3	24.5	25.3	21.1	27.8	41.3	53.6	23.4	41.4	23.4
34.0	33.8	10.1	22.9	56.6	39.0	34.0	23.2	52.6	27.0
27.2	34.2	21.9	17.0	57.0	51.3	42.4	54.8	51.3	42.0
26.3	28.1	16.3	26.0	46.7	54.3	45.1	46.1	60.9	48.3
44.2	28.0	29.9	34.2	57.0	58.8	37.5	41.2	46.9	29.6
31.3	36.7	41.3	39.5	32.6	30.3	21.9	30.7	33.5	32.7
50.0	41.5	40.7	26.5	28.0	23.8	27.6	13.0	35.9	36.4
58.9	45.5	30.5	11.1	28.1	23.3	17.6	30.3	32.4	47.6

Figure 4: Plan view of top of 32% model showing array of 100 linear proportions

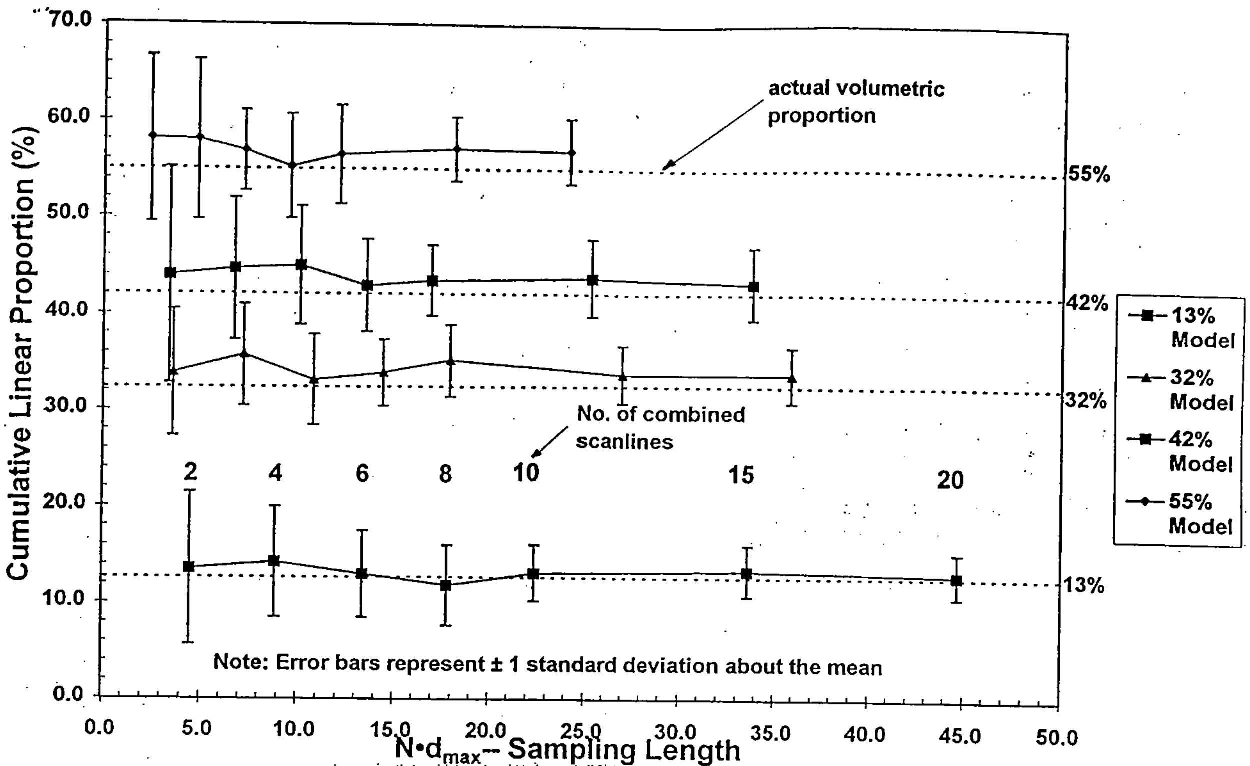

Figure 5: Plot of Cumulative Linear Proportions vs. N* d_{max} for "deep" scanlines. Vertical bars represent mean and standard deviation of clusters of data derived from randomly combined scanlines.

2.3 *Randomization Trials*

Each set of 100 data generated from the long and short exploration scanlines for each model provided an "exhaustive data set", from which sub-sets of boreholes were randomly selected in a "Monte Carlo" approach, employing a specially-written computer spreadsheet routine. Initially, the randomization modeled the real situation of drilling at arbitrarily-selected locations at a site, by randomly selecting two scanlines from the exhaustive date set for a particular bim model, and ignoring the other 98 data points. For this case, the cumulative block linear proportion for the two scanlines was computed and recorded as an estimate of the block volumetric proportion. The exercise was then repeated, with another 2 scanlines being selected from the set of 100, and a new cumulative linear proportion computed. Altogether, 40 such randomizations were performed using sub-sets of two combined scanlines for each randomization.

The randomization exercise was performed using sub-sets of 2, 4, 6, 8, 10, 15 and 20 combined scanlines, repeating each randomization 40 times for the long scanlines ("deep boreholes"), In the case of the short scanlines, sub-sets of 2, 4, 6, 8, 10, 15, 20, 37, and 48 combined scanlines were used, repeating each randomization 40 times. The investigation of each model thus required a total of up to 3400 random selections from the exhaustive data set of 100 scanlines generate for that model.

As the numbers of scanlines in each sub-set increased, so did the probability of including scanline data more than once in each randomization sub-set. It is estimated that the occurrence of duplications was of the order of 10 percent.

2.4 *Statistical Analysis*

The data for each sub-set were scatter plotted as the cumulative linear proportion (y-axis) against $N*d_{max}$ (x-axis). $N*d_{max}$ is the total length of sampling used for each point expressed as a multiple of the length of the largest block used in the model (d_{max}). The range in $N*d_{max}$ was from about 3.6 cm (for sub-sets of 2 long scanlines) to greater than 33.0 cm (for sub-sets of 20 long scanlines). For short scanlines, the range in $N*d_{max}$ was from about 1.2 cm to greater than 37.0. cm.

For each set of randomization trials (2, 4, 6, 8,...20), the clusters of cumulative linear proportions were characterized by their mean and standard deviation. Some data points strayed far beyond two standard deviations from the means, but as sampling length increased ($N*d_{max}$ increased), there was reduction in the scatter as indicated by the shortening error bars (which are plus and minus one standard deviation in length.) The trend of the means of the clusters of data for the four models were close to the actual block volumetric proportions, even for small N^*d_{max} as shown in Figure 5.

3 DETERMINATION OF UNCERTAINTY

The ratio between the standard deviation (SD) in the cumulative linear proportion data and the actual volumetric proportion (Vv) of each models was calculated. The ratio of SD/Vv is here considered a measure of uncertainty. Figure 6, which shows the ratios of SD/Vv plotted against N^*d_{max}, is a convenient tool to estimate the uncertainty. It is apparent that as volumetric proportion increases, the SD/Vv ratio decreases. In other words, as the number of blocks increases in any given volume of melange, more blocks are measured, which increases the sample population. Also, as N^*d_{max} increases, the SD/Vv ratio decreases, because as the sampling length (total length of core measured) increases, more blocks are measured.

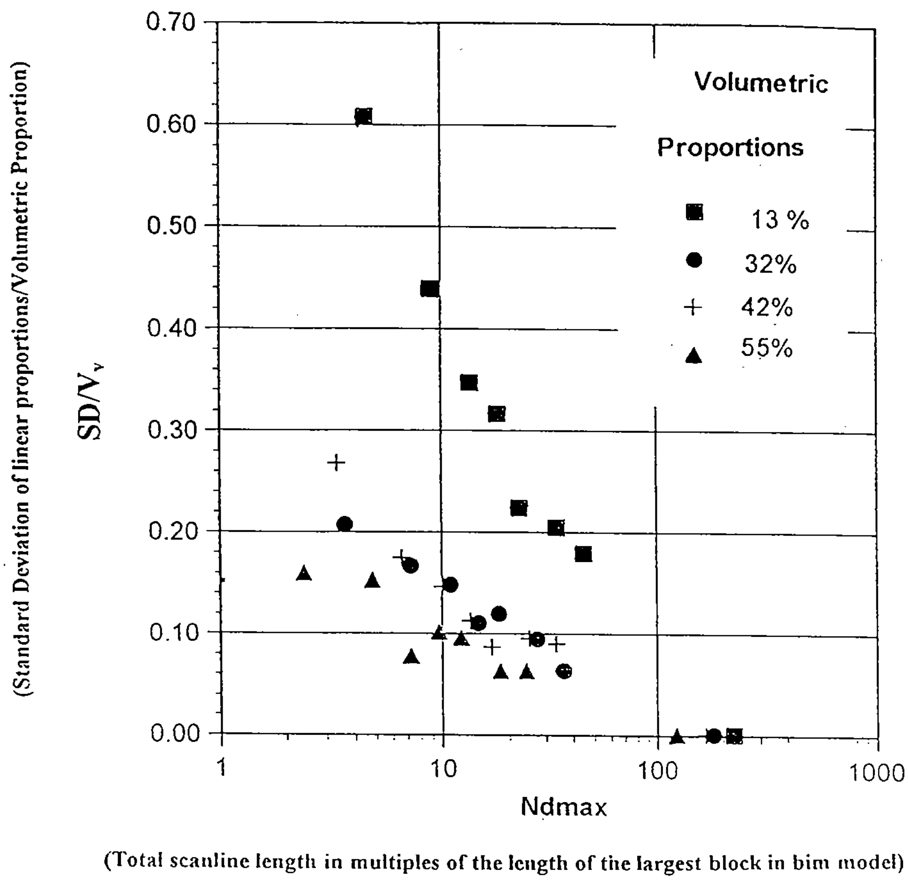

Figure 6: Uncertainty in block volumetric proportion as estimated by cumulative linear proportion vs. sampling length and true block volumetric proportion

The short scanlines yielded data dissimilar to that of the long scanlines, and the cumulative linear proportion calculated from the short scanlines were generally different from the actual volumetric proportions. However, these results are reasonable: the blocks were not uniformly distributed throughout the models. Clearly, scanlines (drill core) will not predict the volumetric proportion of a mass of bimrock that extends beyond the limits of the exploratory scanlines (boreholes).

For particular "true" block volumetric proportions (V_V) and for any particular total length of scanline measurements (i.e.: N^*d_{max}), the cumulative linear proportion data varied considerably. Consequently, it is clear that even with a great total length of drilling (large N^*d_{max}) it is possible to explore a melange rock mass and calculate a cumulative linear proportion that is either higher, equivalent or lower than the true volumetric block proportion. It is thus imprudent to assume the equivalence of cumulative linear proportions to block volumetric proportions without due regard for the uncertainty.

Use of too high a value of the block volumetric proportion leads to an over-estimate of the frictional component of melange strength (ϕ) and an under-estimate of cohesion (c), if that parameter is of interest. The relationships between block volumetric proportion and melange strength are discussed by Lindquist (1994) and Lindquist and Goodman (1994).

4 APPLICATION OF METHOD

The initial purpose of the study was to identify the uncertainty related to an exploration program of core drilling in Franciscan melange rock mass below a dam in northern California. The target length of core to be recovered was between about 300 m and 430m. In terms of d_{max} (the length of the largest expected block in the foundation rock mass) the target length was about $10*d_{max}$ since d_{max} had been estimated as being 30 m to 43 m long. However, the recovery of core from the drilling program was poor and the actual amount of recovered drill core was of the order of 150 m (about $5*d_{max}$) Based on the core recovered, the cumulative block proportion was estimated as 40%.

For a total core recovery equivalent to d_{max}. of 5, Figure 6 shows, for a calculated cumulative linear proportion of 40 percent, that SD/Vv is about 0.2. Consequently, a prudent estimate of the volumetric proportion, incorporating the uncertainty, would be 32% (or, Vv-0.2*Vv = 40% - 0.2*40%).

The research had showed that there were domains in the model bimrocks where block proportions were low, even for models with high overall volumetric block proportion. For the real melange at the dam site, the geotechnical engineering implication of this finding was that there could be geomechanically "strong" regions and "weak" regions in the underlying melange, since melange strength is directly related to the volumetric proportion of blocks. In similar circumstances, it would be justified to identify if such regions are persistent and throughgoing in the melange, perhaps by using a geostatistics approach whereby linear proportion data for different horizons within the melange are contoured in order to discriminate "weak" trends.

CONCLUSIONS

The use of physical model bimrocks allowed the discovery of simple relationships between measured cumulative block linear proportions, linear sampling length and true block volumetric proportion. For in-situ melange rock masses, the initial estimates of block linear proportions can be adjusted to yield a lower and prudent measure of the block volumetric proportion, which in turn can be used to determine appropriately conservative strength parameters in the case of geotechnical engineering design. (On the other hand, less conservative estimates are recommended when predicting block volumetric proportions for earthwork and tunneling construction estimates.)

Since many geological processes produce fragmented and mixed rock, it is suggested that the lessons learned from the study may be valid when working with other bimrocks such as breccias, lahar deposits, complex blocky rock with significant discontinuity infillings, saprolites; and bimsoils such as colluvium and glacial tills.

Geostatistical analyses would be particularly well suited to confirm and extend the preliminary findings of the completely empirical study reported here.

ACKNOWLEDGMENTS

The author is indebted to his colleague Alex Gantvarg who performed the randomization trials. The work was partly funded by Pacific Gas & Electric Co., San Francisco. Merci á mon ami Maestro Michel Slaughter, qui fait le Résumé comme d'habitude, et plus merci á M. Roland Huet pour la même.

REFERENCES

Lindquist, 1994a; The mechanical properties of a physical model melange: in Proc. 7th Congress of Int. Ass. Eng Geol., Lisbon, Portugal; A.A. Balkema, Rotterdam

---, 1994b; The strength and deformation properties of melange: Dept. Civil Engineering, Univ of California, Berkeley, PhD diss.; 264 p.

Lindquist, E.S. and Goodman, R.E., 1994: The strength and deformation properties of a physical model melange: in Proc. 1st North American Rock Mechanics Conference (NARMS), Nelson, P.P. and Laubach, S.E., A.A. Balkema, Rotterdam.

Medley, E., 1994a; The engineering characterization of melanges and similar block-in-matrix rocks (bimrocks): Dept. of Civil Engineering, University of California at Berkeley, California; PhD diss.; 387 p.

---, 1994b; Using stereologic methods to estimate the block volumetric proportion of melanges and similar block-in-matrix rocks (bimrocks): in Proc. 7th Cong. Int. Assoc. Eng. Geol., A.A. Balkema.

Medley, E. and Goodman, R.E., 1994; Estimating the block volumetric proportion of melanges and similar block-in-matrix rocks (bimrocks): Proc. 1st North American Rock Mechanics Conf.; Nelson, P.P. and Laubach, S.E.; A.A Balkema, p. 851-858.

Medley, E., and Lindquist, E.S., 1994; The Engineering Significance of the Scale-Independence of Some Franciscan Melanges in California, USA; 35th US Rock Mech. Symp. Daemen, J.K., and Schultz, R.A.; Balkema, Rotterdam, p. 907-914.