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Strength and deformation properties of a physical model melange

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ABSTRACT: Physical model melanges made up of stronger stiffer blocks in a weaker softer matrix were created to study the effect block proportion and orientation have on melange mass strength and deformation properties. Test results indicate that increasing the block proportion generally results in a decrease in cohesion, an increase in angle of internal friction and an increase in modulus of deformation. The highest block proportion specimens have a cohesion as low as half of that of the matrix and an angle of internal friction as much as 16.5° higher than that of the matrix. Block orientation also affects the strength, most notably the cohesion, and the modulus of deformation. The specimens with the most adversely oriented blocks (30°) have the lowest cohesion, and the increase in modulus with block proportion is most pronounced for the models with vertically (0°) oriented blocks and least pronounced for those with horizontally (90°) oriented blocks.

1 INTRODUCTION

Melange is the French word for "mixture" and is defined by Bates and Jackson (1984) as, "a mappable body of rock that includes blocks of all sizes, both exotic and native, embedded in a fragmented and generally sheared matrix." In essence, therefore, a melange is a rock body made up of stronger blocks in a weaker matrix (i.e. a block-in-matrix rock or bimrock). Other examples of bimrocks are conglomerate and sheared serpentinite.

Due to their complex nature, melanges are difficult materials with which to work. D'Elia, et al. (1984) state the following regarding the "Argille Scagliose" (an Italian melange unit), "Given the lithologic and structural characters of the "Argille Scagliose" it was not possible to carry out laboratory or in-situ tests capable of providing data on the mechanical properties of the mass formation." This fact has been realized by many engineers and geologists working with melanges all over the world. The reasons for this difficulty include:

1. Obtaining "undisturbed" samples of a mixture of harder blocks in weaker matrix is virtually impossible by coring. The drilling resistance of the harder and softer materials are significantly different. This difference in drilling resistance can cause the harder materials to gouge into the weaker materials resulting in significant sample disturbance or even a complete loss of the weaker material.

2. Even if one were able to recover an undisturbed sample, it is a virtual impossibility that the sample would be representative of the melange mass of interest. The testing of large in-situ samples is perhaps the most promising approach to finding a representative specimen, but even this possibility seems remote.

Common engineering practice has been to design for the strength and deformation properties of the weak matrix. In some cases this might prove to be overconservative, though. For these reasons, a different approach for determining the strength (cohesion and angle of internal friction) and stiffness (modulus of deformation) of a melange needs to be developed. It has been found that it is possible to recover and test samples of pure matrix and pure block. Given the mechanical properties of these two components and some other properties of the melange mass (namely the volumetric proportions of the two components and the orientation of the melange fabric), it may be possible to estimate a melange's mass properties. For example, Volpe, et al. (1991) suggest that the strength of a melange mass can be represented by the weighted average of the strengths of the weaker matrix and the stronger blocks based on their volumetric proportions. Unfortunately, this approach has no theoretical basis. This research has used physical model melanges to study the effect of block proportion and fabric orientation on the strength and stiffness of some model melanges.

2 PHYSICAL MODEL MELANGES

Melanges tend to have a foliation due to both block alignment and prevalent shearing around the blocks. This is an important structural characteristic because, as both Jaeger (1960) and Donath (1964) discuss, anisotropic rock has marked anisotropic strength characteristics. The physical models therefore incorporate oriented blocks and mock shearing. The model block shape and size distribution are based on personal observations of melange made along California's north coast and various photographs and descriptions of melanges from around the world.

Cemented soils were chosen as the materials to model both the block and matrix components. A sand-portland cement-fly ash mixture was used for the blocks and a bentonite-portland cement mixture for the matrix. Thin layers of wax coated with talcum powder were used to model matrix shearing.

Six-inch diameter cylindrical specimens of model melange have been fabricated and tested triaxially to determine their Mohr-Coulomb strength parameters and stress-strain behavior. Models with four different block orientations, each with three block proportions, were created. Figure 1 schematically shows the different model types. The arrows in the diagram indicate the axial loading direction, and the angle indicated (0°, 30°, 60° or 90°) is simply the angle between the axial loading direction and the orientation in which the blocks are aligned.

Five specimens of each type, along with 7 6-inch diameter pure matrix and 10 2-inch diameter pure block specimens were created. This means a total of 67 6-inch diameter specimens and 10 2-inch diameter specimens were tested for this study. These numbers do not include all of the trial mixes required to finalize the model materials and specimen preparation methods. In total, over 100 6-inch diameter and 80 2-inch diameter specimens were tested.

3 TEST RESULTS

3.1 Effect of block proportion and orientation on strength

The Mohr-Coulomb strength parameters, cohesion (c) and angle of internal friction (ϕ), are used to represent the physical models' strengths. Table 1 presents the results for all specimen types.

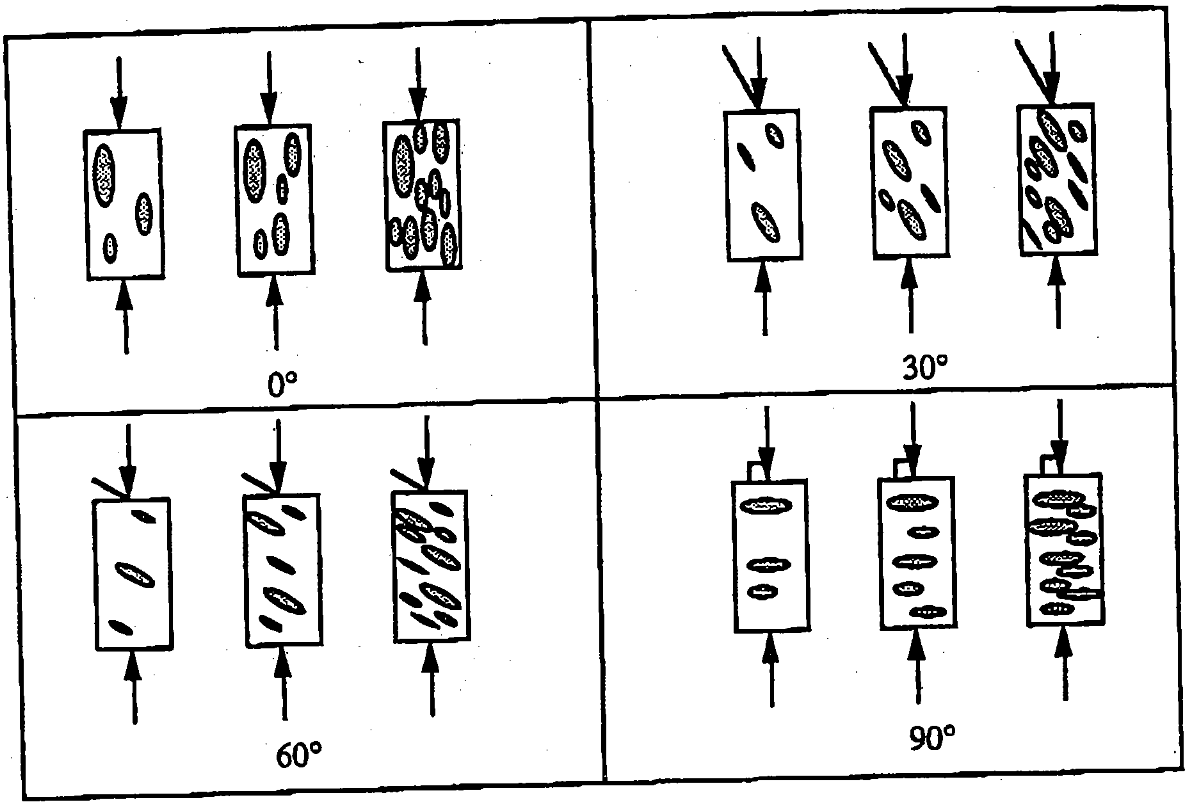

Figure 1. Specimen Types

Table 1. Values of cohesion and angle of internal friction

Block orientation	Average block proportion	c (psi)	ϕ (°)
N/A	0%	330	24.7
N/A	100%	445	38.3
0°	29%	345	26.2
30°	31%	250	32.9
60°	33%	377	23.4
90°	29%	276	32.8
0°	50%	233	33.5
30°	53%	206	32.3
60°	54%	229	33.3
90°	57%	231	37.6
0°	72%	199	39.6
30°	74%	163	38.2
60°	73%	180	41.2
90°	71%	302	34.0

The effect of block proportion on cohesion is summarized by Figure 2. This plot shows that as the block proportion increases, the cohesion generally decreases. In fact, the specimens with high block proportions (approximately 70 percent) have a cohesion only about half that of the matrix alone.

As discussed previously, Jaeger (1960) and Donath (1964) found that fabric

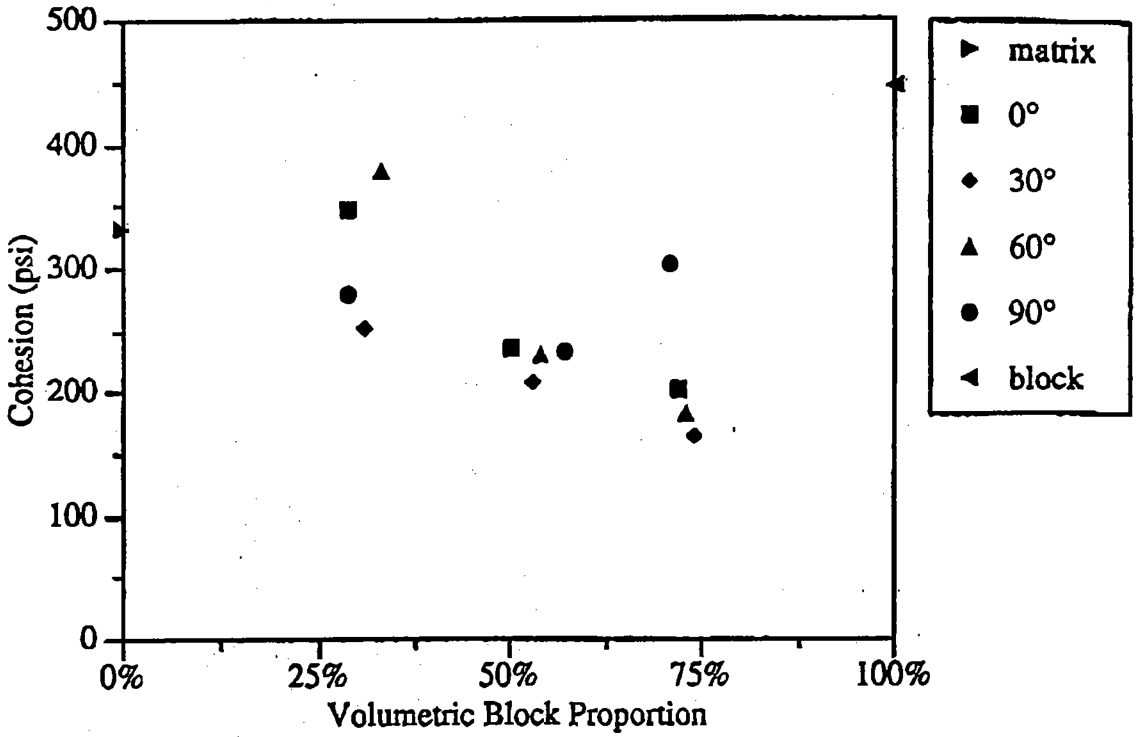

Figure 2. Cohesion versus volumetric block proportion

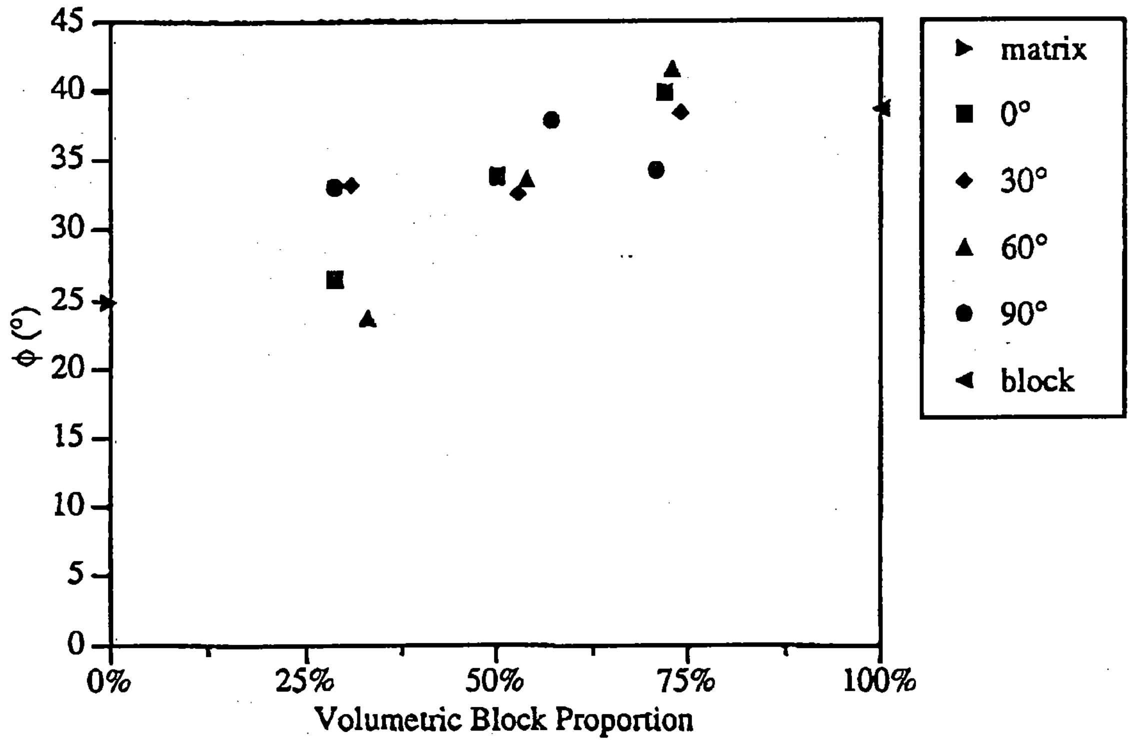

Figure 3. Angle of internal friction versus volumetric block proportion

anisotropy creates strength anisotropy in rocks. When planes of weakness (e.g. cleavage or shears) are oriented "adversely" with respect to the loading the result is a significantly lower strength. The block-in-matrix models used in this study are anisotropic due to the orientation of the larger blocks in each specimen. Although the "foliation" created by orienting the blocks is not nearly as strong as that formed by, for example, slaty cleavage, it still results in at least minimal strength anisotropy. Note that the specimens with blocks oriented at 30° to the axial loading direction (the most "adverse" orientation tested) have the lowest cohesion when compared to the models with similar block proportions and different block orientations.

Figure 3 clearly shows that the angle of internal friction increases with increasing block proportion. This increase is as much as 16.5° for the 60° orientation high block proportion specimens over the pure matrix specimens.

The values of angle of internal friction for the medium and high block proportion specimens do not vary very significantly with block orientation. This corroborates the assertion by Goodman (1989) that, "the variation of the friction angle with direction proves generally less severe than the variation of the shear strength intercept," in anisotropic rock.

Another observable result is that the low block proportion specimens show evidence of a threshold block proportion below which the presence of blocks has little effect on strength. Note that the cohesion and angle of internal friction for the 0° and 60° specimens are very close to those of the matrix material, while the 30° and 90° specimens have much lower cohesions and higher angles of internal friction. These data suggest that this threshold may be close to 30%. Evidence of a similar threshold has been found for heterogeneous soils. Heterogeneous soils are mixtures of coarser particles in a finer grained matrix, much like a melange. In fact, based on a review of the heterogeneous soil literature and some of their own laboratory work Irfan and Tang (1993) propose a threshold volumetric block proportion for heterogeneous soils of 25%.

Looking at the failed specimens provides an explanation of how the block proportion affects the cohesion and angle of internal friction. The failures tend to form along the block-matrix contacts rather than through the blocks even though the blocks are only about twice as strong as the matrix in unconfined compression. The block-matrix contacts are surfaces of weakness just as they are in real melange. The specimens with a higher block proportion therefore have a higher density of weakness surfaces resulting in a lower cohesion. On the other hand, the angle of internal friction increases because the failure surface becomes more tortuous (it has to fail around more blocks) at higher block proportions. An increase in tortuousity of the failure surface due to the presence of blocks in bimrocks has been hypothesized but never demonstrated in the past by D'Elia, et al. (1988) for melange and Savely (1990) for conglomerate.

Another interesting discovery that can be made by studying the failed specimens is that the failure surface only rarely passes through the blocks. For this reason it does not appear that the strength (cohesion and angle of internal friction) of the blocks plays a role in the strength of the mass so long as the blocks are stronger than the matrix. The strength contrast between the blocks and matrix required to prevent failure through the blocks is not known, but, as was stated previously, in this case the blocks were only about twice as strong as the matrix in unconfined compression which indicates the strength difference certainly does not have to be immense.

3.2 Effect of block proportion and orientation on the modulus of deformation

The modulus of deformation is defined in this study as the slope of a line drawn from the origin on the stress-strain plot to the point on the virgin loading curve corresponding to 40 percent of the maximum stress difference ($(\sigma_1-\sigma_3)_{max}$). This measure is typically called the secant modulus. The term modulus of deformation is used rather than the modulus of elasticity because during virgin loading the specimen undergoes both recoverable (elastic) and nonrecoverable (plastic) deformations.

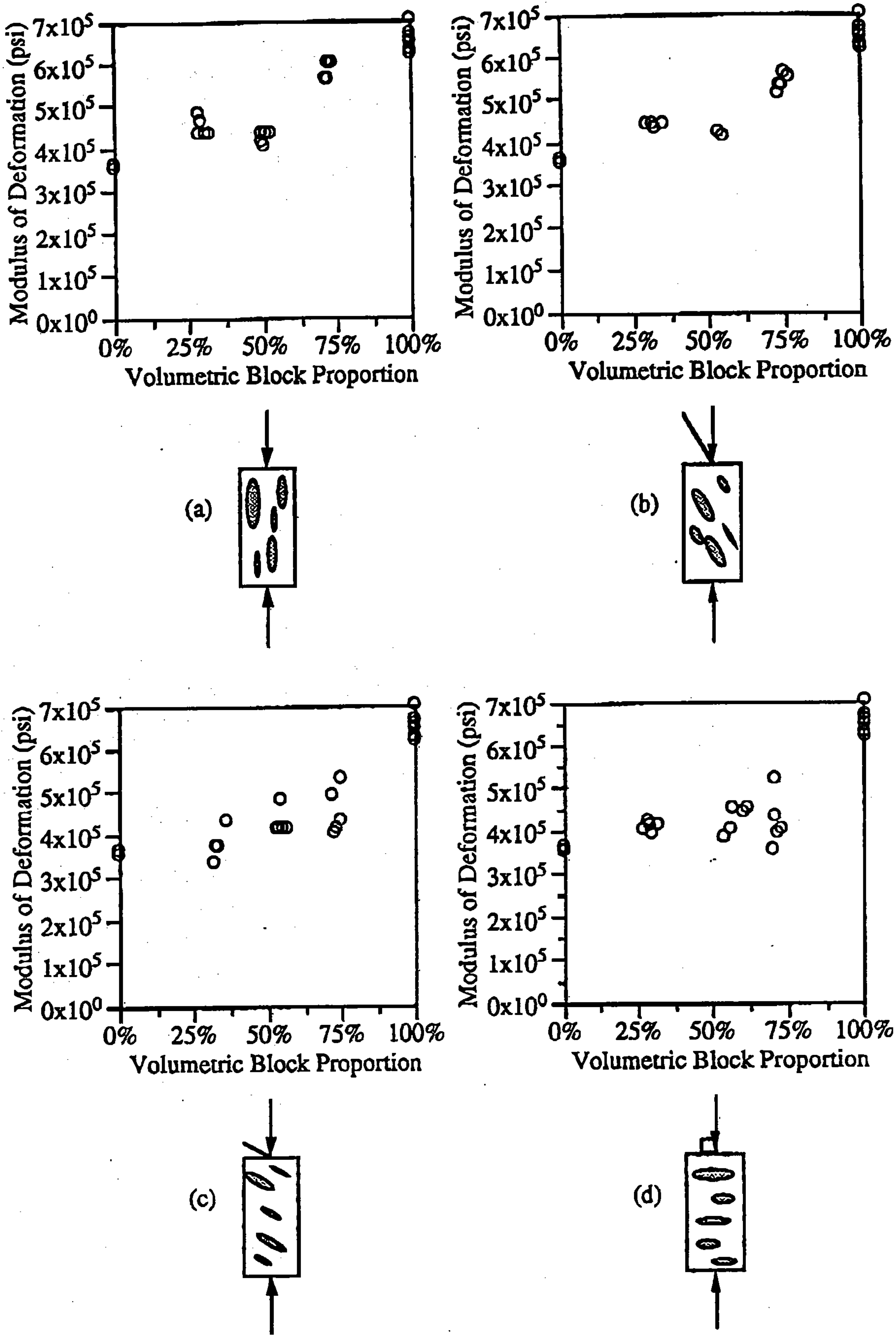

Figure 4. Modulus of deformation versus volumetric block proportion (a) 0° (b) 30° (c) 60° (d) 90°

Figure 4 shows that increasing the block proportion generally increases the modulus of deformation of the models. Each plot is for a different block orientation as indicated by the schematic specimen sketch below each plot. Note that the medium (approximately 50 percent) block proportion specimens with 0° and 30° block orientations fall below the trend set by the low and high proportion specimens. It has yet to be determined why this behavior was exhibited.

This increase in modulus is expected because as the block proportion is increased, the volume of stiffer inclusions in the softer matrix is increased, resulting in a stiffer model. Normal strength concrete can be viewed as a sort of melange (i.e. it is made up of stronger aggregate in a weaker matrix), and similar increases in modulus have been reported in the concrete literature for many years.

Another finding evident in Figure 4 is that the rate of increase in modulus with block proportion decreases as the block orientation is rotated from vertical to horizontal. This result is also not unexpected. Simple models such as the one proposed by Hirsch (1962) for concrete can be used to show that when the blocks are vertically inclined they attract more of the axial stress. The result is a stiffer model. A second reason why the increase in modulus is smaller for the specimens with horizontally oriented blocks is wax layer alignment. Aligning the blocks tends to align the wax "shears" resulting in subparallel layers of wax in the specimen. As these layers are rotated closer to horizontal they significantly reduce the stiffness of the model.

4 SUMMARY AND CONCLUSIONS

Triaxial tests on physical models indicate that the strength and deformation properties of a melange are significantly affected by block proportion and fabric orientation.

The test results indicate that the cohesion decreases and the angle of internal friction increases with increasing block proportion, and the strength, particularly the cohesion, decreases as the block orientation becomes more adverse. It is postulated that the strength parameters are affected in these ways because the failures form along the block-matrix contacts.

The test results also indicate that the modulus of deformation increases with increasing block proportion and this increase is greatest for specimens with vertically (0°) aligned blocks and smallest for specimens with horizontally aligned blocks (90°).

Given this information, it is clear that the block proportion is an important value to determine in the field. Some ideas on how this value can be determined are given by Medley and Goodman (1994). It must be remembered, though, that melange in the field can be significantly more complex than the models used in this study, and many factors beyond the block proportion and fabric orientation may be important. For example, one may find major zones of sheared material that will play an important role in the field behavior. Even so, it is believed that the basic behavior exhibited by these models is indicative of that which will be found in actual melange.

5 ACKNOWLEDGMENTS

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