DISCUSSION

O. S. Cecil[1] *(written discussion)*—Dr. Rocha presented results from dilatometer tests that were conducted in vertical drill holes above a horizontal tailrace tunnel in Brazil. For what purpose were these tests conducted, and how, specifically, was the information used in design?

Also, for what types of projects are the dilatometer and flatjack modulus tests expected to be used? Sketches of civil engineering structures and the proposed test setups would be helpful in explaining this question.

M. Rocha (author's closure)—As indicated in the final version of my paper, the purpose of the tests was to investigate the change of deformability with depth, with a view toward correlating the test results with the geologic data yielded by the cores sampled in the boreholes. It was concluded that the rock mass has a rather high modulus of elasticity at the depth planned for the powerhouse and the tailrace tunnel.

As I had occasion to emphasize, the use of the dilatometer will make it possible to obtain, preferably during the geologic exploration, an estimate of the deformability of the rock mass; on the basis of this estimate the rock mass can be zoned and the deformability of each zone can be subsequently determined by the flatjack method. In the case of deep tunnels or other deep openings to which the access to the zones where the structure will be built is difficult, tests with thin flatjacks can be performed in zones nearer the surface considered (on the basis, especially, of dilatometer tests) as representative of the deep zones; these zones can then be tested when they are made accessible during the construction. Additionally, as more experience is gathered with the use of dilatometers, it will be possible to use known correlations applicable in the case under consideration.

W. S. Brown[2] *(written discussion)*—In his very interesting and informative paper Dr. Rocha presented deformation modulus results[3] from thin

[1] Missouri River Division Laboratory, Corps of Engineers, U.S. Army, Omaha, Neb. 68102.

[2] Head, Structural and Rock Mechanics Section, Division of Research, U.S. Bureau of Reclamation, Denver, Colo. 80225.

[3] Rocha, M., "New Techniques for the Determination of the Deformability and State of Stress in Rock Masses," presented at International Symposium on Rock Mechanics, Madrid, 1968.

flatjack tests (p. 52). The modulus results vary with the number and the position of the jacks. The author attributes the lower modulus near the surface to a lower capacity of the rock mass in that location. The trend of the data with position indicates that the stress field and edge restraint may be a more significant reason for the low modulus values near the surface.

The test results show that data obtained near the edges of the slot (both sides and bottom) always result in higher modulus values. This is due to the restraint provided by the rock mass and indicates that a longer and deeper slot is necessary to develop a plane stress field. It is not clear that the author's calibration of the thin flatjack could account for this problem, since apparently all jacks were calibrated in the same calibration block.

Examination of the modulus data given above shows that when loaded one at a time the center jack gave a lower modulus than the outside jacks. This should be expected since the restraint provided by the slot is higher at the edges. This is verified by the two-slot tests where use of the center jack with either of the outside jacks gave reasonable agreement.

It is interesting that the modulus values decreased as the number of jacks in a test increased. However, it is disconcerting to see that the incremental difference in modulus becomes larger rather than smaller as the number of jacks is increased. One would certainly expect to reach an asymptotic value and the limited results from three tests does not indicate such a trend. It would be worthwhile to extend the test results with several more flatjacks to insure that the results approach an asymptotic value. This may be helpful in determining how many jacks are really necessary to give reliable results.

M. Rocha (author's closure)—Professor Brown has raised a very pertinent question, namely, to what extent does fracturing of the rock in the plane of the thin flatjacks invalidate the representation of the equilibrium by that of a quarter-space. In fact applications of the method after the Denver symposium have shown that sometimes insufficiently developed fracturing that depends on the tensile strength of the rock mass and on its initial state of stress is observed. Meanwhile, the influence of the extent of the development of fracturing on the moduli of elasticity obtained was investigated by analytical means.

In the case of the results under consideration an influence of the edge restraint is quite possible. Nevertheless, as regards the lower moduli yielded by the deformeters placed nearer the surface, it should be noted that a certain weathering of the rock mass near the surface was disclosed by the core samples.

Regarding the other comment, namely, the decreasing value of the modulus of elasticity for larger volumes of the rock mass influenced by the test, I think that this marked decrease of the modulus when the number of flatjacks increased from two to three is due to the presence of a joint at a certain distance from the slots. As for the number of flatjacks required to obtain a representative value of the deformation, there is no general rule. It depends on the accuracy required for the value of the deformation, or the heretogeneity of the rock mass, and on the distance between joints and other fracturing. Thus each case has to be assessed separately.