BIDIMENSIONAL GEOMECHANICAL MODELS OF LARGE UNDERGROUND OPENINGS

Pier Paolo Rossi

ISMES - Bergamo

1. FOREWORD

The physical model represents a very useful tool for the study of the problems concerning the excavation of large underground openings.

Wide-ranging experimental research in this field is being carried out at ISMES in collaboration with the Research Department of ENEL.

Bidimensional models in reduced scale have been studied to investigate the effect of the excavation on a rock mass with a constant value of the state of stress applied.

The most difficult problem to solve is the choice of a model material which is able to reproduce with sufficient reliability the characteristics of a rock mass. Additionally, hardly less intricate are the problems related to the loading and measuring techniques.

In a first stage of the research the problem was simplified by the use of a model material with characteristics of homogeneity and isotropy. This initial semplification relative to the model material facilitated the setting up of the loading and measuring techniques.

After this preliminary phase, attention was directed to the study of the model material and to the development of a testing technique for a more realistic reproduction of a rock mass. The research has centred on the study of discontinuous rock masses with a regular set of joints obtained by assembling together small brickets. A range of experimental investigation has been carried out to determine the physical-mechanical characteristics of the material as well as the characteristics of the joints reproduced in the model.

2. MODELS WITH HOMOGENEUS ISOTROPIC MATERIAL

In this initial phase of the research a pumice concrete mortar as model material was employed. Slabs having dimensions 100 x x 100 x 20 cm were cast and a biaxial state of stress was applied to the model by means of rubber pressure bags containing oil. The excavation of the underground opening was realized step by step, by means of a series of adjoining holes, while the state of stress applied to the slab was mantained constant (fig. 1).

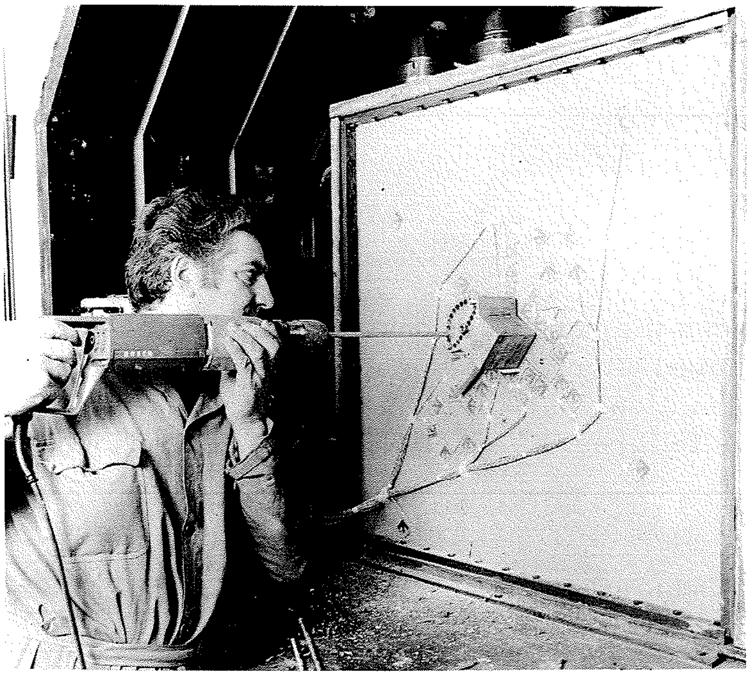


FIG. 1

Technique of excavation of the opening by means of adjoining holes

Fig. 2 shows the model in scale 1:200 of the pumped-storage power station of Entracque. Visible around the excavation are the measuring points - for demountable extensometer - which reproduce the multibase extensometers installed in the prototype. On the other face strain-gauge rosettes are installed; these provide the stress distribution around the excavation.

It must be observed that in this kind of model the material around the excavation behaves quite elastically. This is confirmed by the agreement found between the results of physical models and those of linear-elastic finite elements model. By way of example, Fig. 3

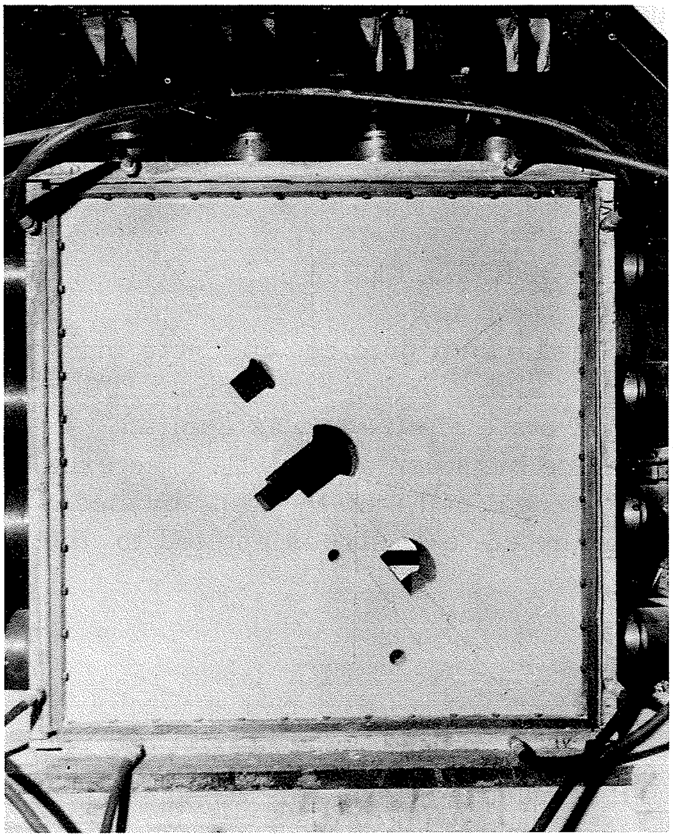


FIG. 2

View of the model of the Entracque power station

shows a comparison between the results of physical and finite-element models relative to the pumped-storage power station of Lake Delio. The diagrams of the deformations in a direction normal to the surface of the opening are relative to three different phases of excavation.

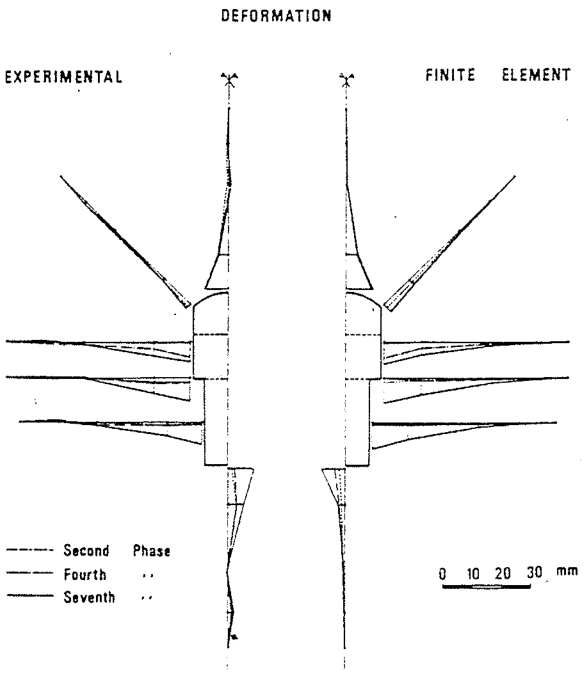


FIG. 3

Comparison between physical and finite-element models

3. EXPERIENCES WITH DISCONTINUOUS MATERIAL

Following the above mentioned phase of the research, which was extremely useful for the setting up and betterment of the testing techniques, the possibility of realizing large excavation models on a discontinuous rock mass are currently being verified.

The problem has been simplified by introducing the discontinuities in the rock mass according to a regular scheme. This is obtained by reproducing the rock mass by means of the assembling together of small brickets which are pressed into a special moulder.

Before starting with the model construction, a wide-ranging test program was carried out for purposes of determining both the physical-mechanical characteristics of the model material as well as the joints between the brickets.

The composition of the material, chosen after a series of preliminary tests, is as follows:

Baryte (powder)	82 %
Paraffin oil	10 %
Zinc oxide	8 %

The brickets, moulded at a pressure of 50 Kg/cm^2 have a specific gravity of 2.99 t/m^3.

The size of the brickets can be varied very easily by changing the moulds.

The deformability characteristics of the brickets for uniaxial compressive stress are illustrated in fig. 4. Stress-strain diagrams obtained by tests in a direction normal and parallel to the direction of moulding pressure are shown.

Several loading cycles were effected, with increasing value of stress, up to about 50% of uniaxial compression strength. The figure also provides indications of the secant moduli of deformability calculated at each stress level.

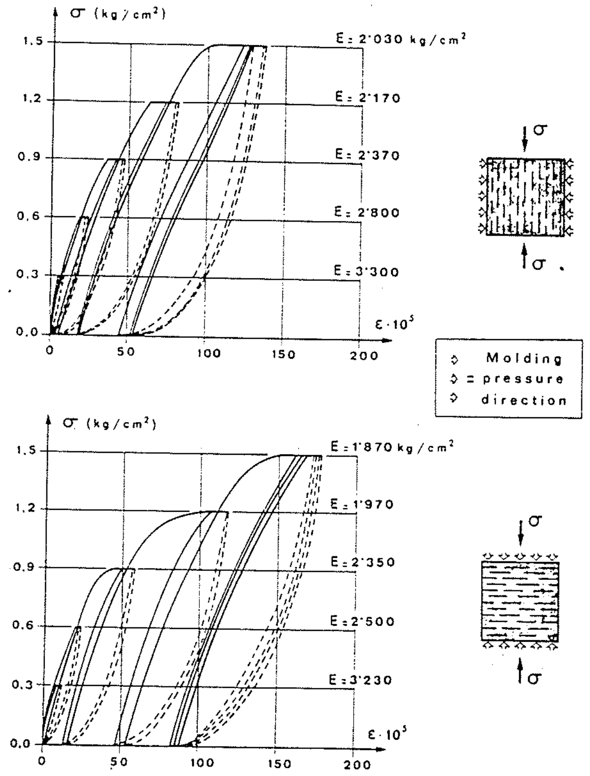


FIG. 4

Stress-strain curves in niaxial compression test with direction normal and parallel to the moulding pressure direction

It may be observed that the material presents a small anisotropy due to the technique of preparation of the brickets; in one direction, parallel to the moulding pressure direction, the deformability is a little higher than in the normal direction.

Fig. 5 summarizes the values of compression and tensile strength. The compression strength is higher in a direction parallel to the moulding pressure, while tensile strength would seem not to be influenced to any extent by the moulding pressure direction.

The results of triaxial tests with confining pressure up to 1.5 kg/cm^2 are shown in Fig. 6.

Direct shear tests on unjointed material have been carried out. As well the stress-displacement curves (Fig. 7) show that a peak strength and a residual one can be identified for normal stress values lower than 2 Kg/cm^2.

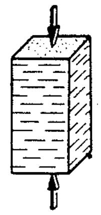
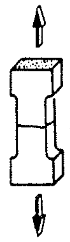
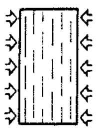
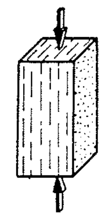
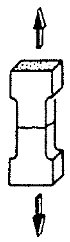
Molding pressure direction	Uniaxial compression strength	Tensile strength
	10 x 10 x 20 cm  $\sigma_c = 3.23$ kg/cm^2	5 x 5 cm  $\sigma_t = 0.28$ kg/cm^2
	10 x 10 x 20 cm  $\sigma_c = 2.62$ kg/cm^2	5 x 5 cm  $\sigma_t = 0.25$ kg/cm^2

FIG. 5

Average values of compres_ sion and tensile strength

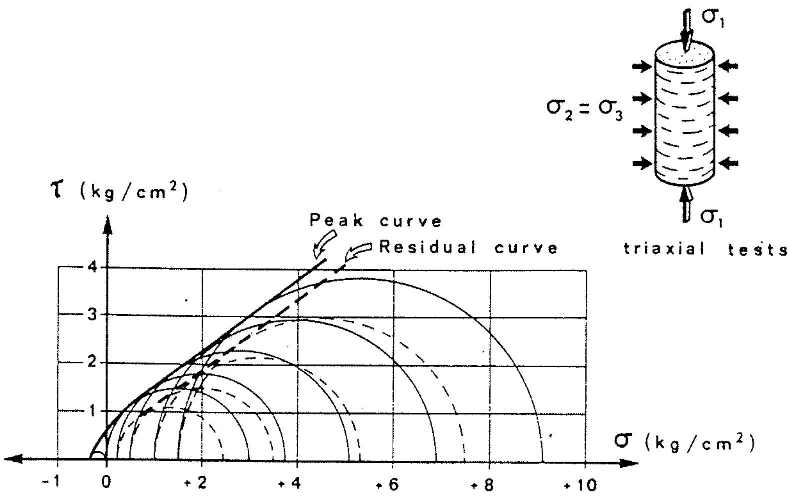


FIG. 6

Triaxial tests results

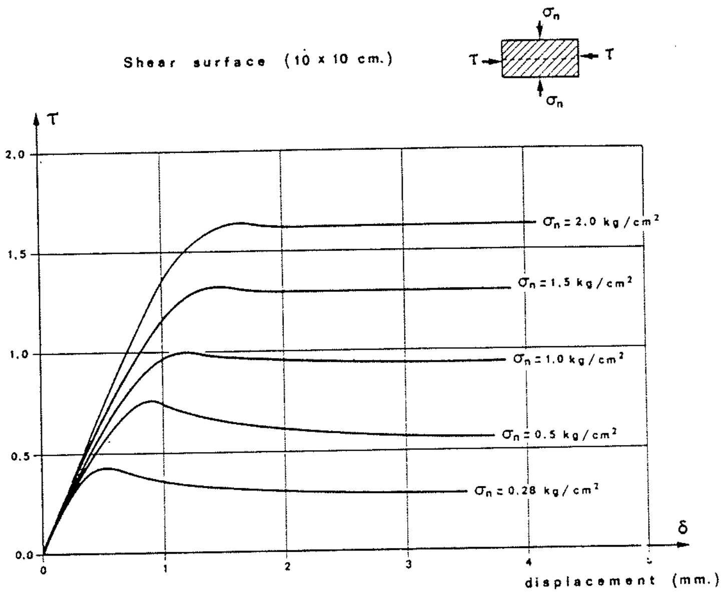


FIG. 7

Direct shear tests on unjointed material

Shear test have also been carried out along the joints be - tween two brickets(Fig. 8). In this case no residual strength is shown by the stress-displacement curves for the reason that the joint is characterized by very smooth contact surface.

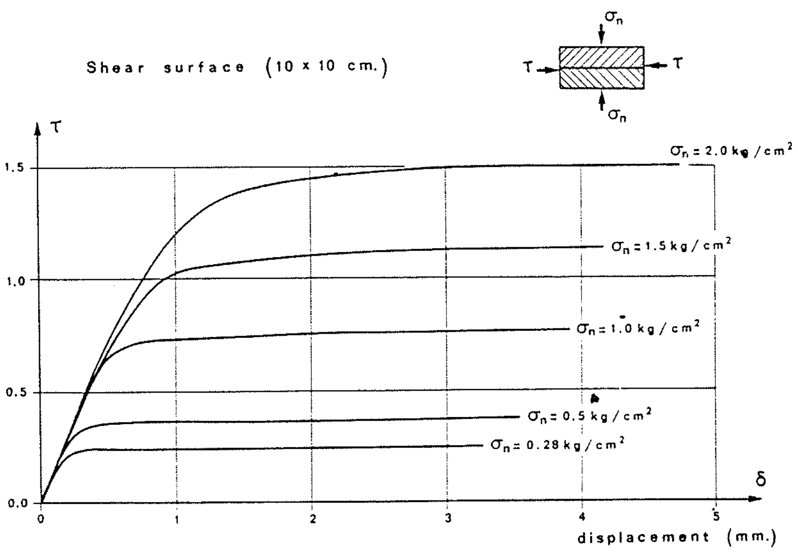


FIG. 8

Shear tests along the joints between two brickets

To reproduce a joint with residual strength characteristics distinct from the peak ones, it would be necessary to reproduce rough-surface joints. A joint of this kind can be realized in a model by producing a brittle failure in the material and putting together the two surfaces.

Fig. 9 shows the variation of the angle of friction along the joints and of the angle of friction of continuous material with the increase of normal load.

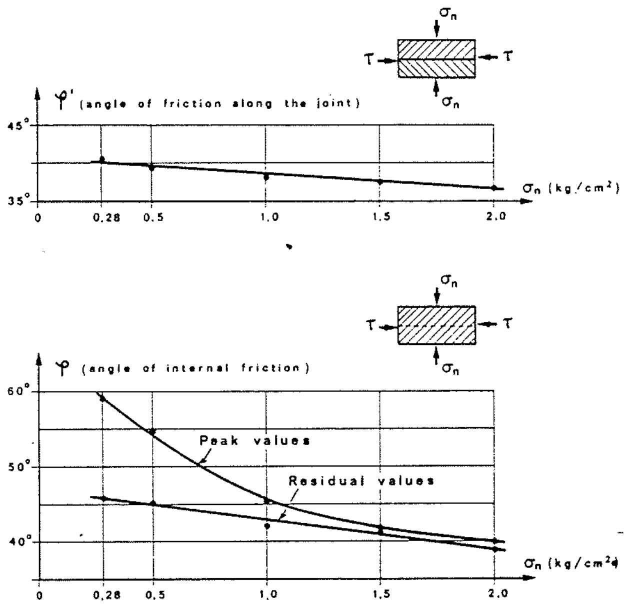


FIG. 9

Variation of the angle of friction with the increase of normal load (σ_n)

Finally, a series of experimental tests have been carried out in order to verify the influence of the number of joints on the deformability characteristics of composite specimens. Uniaxial compression tests were performed on composite specimens with an increasing number of joints across the base of the extensometers. The effet of the parallel joints on the deformation modulus, in a direction normal to the joint surfaces, is summarized in fig. 10.

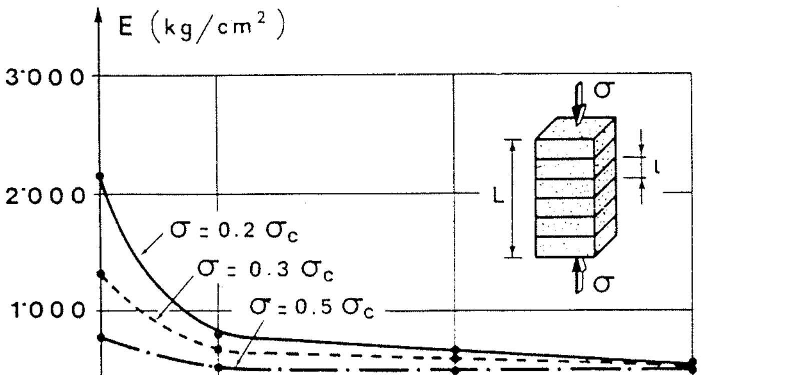


FIG. 10

Uniaxial compression tests on composite specimens

The secant moduli are represented for different stress levels (20, 30, 50% of the uniaxial compression strength of the continuous material). It can be observed that the curves present a considerable initial decrease because of the presence of one joint only; for a higher number of joints the decrease is noticeable only for low stress levels.

Following these research on the model material, a simple bidimensional model was realized to verify on a larger scale the results described above. A slab with dimensions of 100 x 100 x 20 cm was made by assembling brickets sized 10 x 10 x 5 cm, in such a way as to obtain continuous horizontal joints (Fig. 11). The biaxial state of stress was applied by compressed air up to a maximum stress level of 1,5 Kg/cm^2.

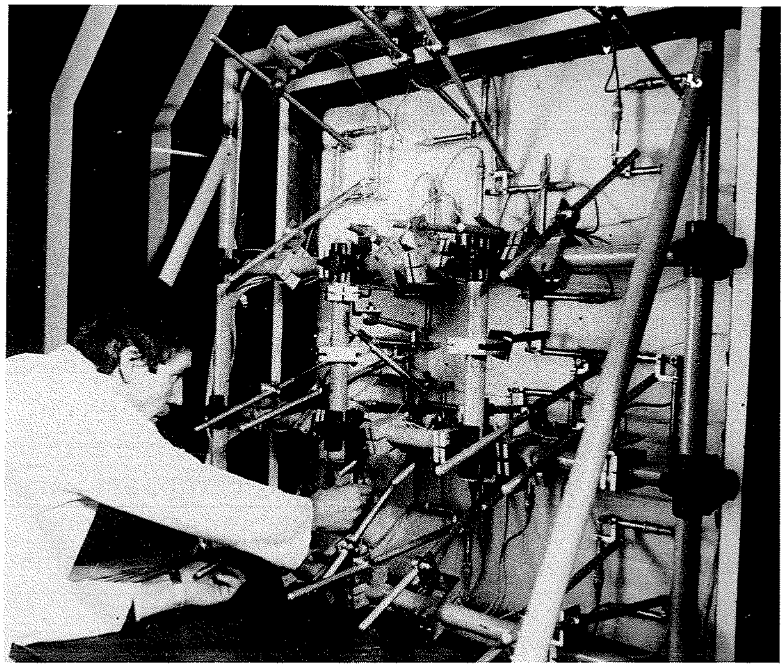


FIG. 11

View of discontinuous model obtained by assembling together brickets. The displacement transducers are visible.

A circular excavation having a diameter of 20 cm, was realized at the centre of the plate, and the deformations around the excavation were measured by means of displacement transducers.

The results obtained by this simple model have been found to be fully satisfactory as regards the behaviour of the material and that of the measuring instruments.

Sussequent steps in this programme include the development of this highly advanced modelling technique with a view to making significant contributions towards the solution of stability problems related to the excavation of large underground openings in difficult geological conditions.