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MEASUREMENT OF EARTH PRESSURES BY MEANS OF THE FLAT JACK TEST

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MEASUREMENT OF EARTH PRESSURES BY MEANS OF THE FLAT JACK TEST

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Summary

"This study deals with the principle and application of a method of measuring the stresses around a rock gallery.

"The measuring principle consists of cutting a drain in a gallery wall, observing the corresponding stress lessening, then restoring the initial state of stress by means of a Freyssinet flat jack. The application of this method in the Eastern iron-ore mines have given interesting results. In particular, they confirm the validity of the elastic hypothesis in these mines and enable the measurement of the stresses within the mass to be made more accurately than by the usual methods. Finally, by means of improvements, which do not unduly complicate the test performance, complete information on the elastic characteristics of the mineral may be obtained."

[Authors' summary]

Introduction

Great progress has been realized since the beginning of this century in the construction methods concerning underground works, in both civil engineering and mining fields. Mine working particularly has evolved considerably in the past twenty-five to thirty years. This progress is due to systematic research in more economical methods through improvement of the material used and a more rational utilization of the mechanical properties of the terrain.

Thus, either to determine the optimum thickness of a gallery lining, or to undertake more productive mining procedures, knowledge of the earth pressures is essential. The purpose of the flat jack test is to measure the stresses in unbroken rock in the vicinity of the gallery wall.

The principle of this test was first considered in the course of conversations that the authors had with Mr. Tincelin [Ingénieur, Services techniques des Mines de Fer de l'Est - Engineer, Technical Services of the Eastern Iron Mines], regarding problems presented to the "Laboratoires de Bâtiment et des Travaux Publics" - [Building and Public Works Laboratories] by the "Chambre Syhdicale des Mines de fer de France" [Committee of the Iron Mines of France].

The study made in the laboratory belongs in the province of research on rock media that was started at the request of "Electricité de France" [Electricity Co. of France].

I. - Classical indirect measurements

A. Generalities

The pressures within a rock mass are generally deduced from the measurement of strain of the material in place. The various phases of the operation are as follows:

(1) A part of the rock in place is isolated so as to free it from the stresses to which it was subjected, and then its deformations are measured.

(2) The laws are determined according to which the stresses and strains are related in the case under consideration.

(3) The stress is deduced from the observed strain.

B. Measurement of deformation

The first phase presents relatively little difficulty. However, in spite of the wide range of extensometers that the experimenter may have at his disposal, the strain measurement has no universal solution. The choice of the strain base and of the sensitivity of the extensometer is generally imposed by the problem to be solved and by the nature of the material; inconsistent conditions are brought about, to say nothing of the difficulties resulting from interfering factors such as moisture or creep. Nevertheless, a trained experimenter may hope to obtain measurements that can be used in most cases.

C. Strain-stress relations

a) Elastic hypothesis.

The second phase is by far the most critical. One always tries to deal with the concept of the elastic medium, whose conditions are recalled as follows:

The medium is:	in the neutral state in equilibrium homogeneous isotropic

The strains are:	small linear reversible

b) <u>Discussion of the hypotheses.</u>

Obviously these conditions are almost never rigorously fulfilled in the rock masses, even though compact. On the other hand, if these hypotheses are approached close enough, two coefficients are sufficient to characterize the deformability of the medium: Young's modulus and Poisson's ratio.

(1) Homogeneity.-The necessity for homogeneity is easy to demonstrate. In a heterogeneous mass, the modulus of elasticity varies with the measurement base or, what amounts to the same thing, with the volume tested. Thus a granite gneiss studied in the laboratory gave the following results:

200,000 kg/cm^2 by setting under resonance a prismatic sample 15 cm long.

250,000 to 350,000 kg/cm^2 by measuring the deformations with a comparator on a 15 cm base.

600,000 kg/cm^2 by measuring the deformations with electrical extensometers on a 1 cm base.

700,000 kg/cm^2 maximum obtained by direct measurement of the speed of sound, the base being free from fissures.

Likewise, the Tignes quartzite behaved in the laboratory as an isotropic material of 590,000 kg/cm^2 modulus, whereas the jack test made on the rock in place, dealing with a mass of the order of a meter, has shown an in-place modulus of only 100,000 kg/cm^2.

These results must not be interpreted as the effect of dispersion, but as the manifestation of a complex phenomenon, that of the deformation of a fissured natural material.

The choice among these values depends upon the problem; evidently it will not be the same for the interpretation of measurememts with the electrical extensometer as for the computation of the deformation of an arch-dam support.

When the mass is not homogeneous, Poisson's ratio will be subject to variations similar to the preceding ones; the measurements will be subject to much larger related errors.

(2) Isotropy - The question of isotropy is still more intricate because the anisotropic influence is difficult to take into account in an elastic computation. However, at times a direct measurement of deformation may be sufficient; for example, for a simple compression in one direction, with measurement of the related longitudinal and transversal deformations. If the test is made again for another direction, possibly in a preferred orientation the estimation of the material's anisotropy will be possible. On the other hand, when a method of indirect measurement is applied, the greatest care is necessary; thus, when one attempts to deduce the modulus of elasticity of the rock from the measurement of the speed of sound propagation, the computation gives the Young's modulus and Poisson's ratio only if the elastic hypothesis

applies. So, in the course of measurements of the speed of sound propagation in rocks, the determination of Poisson's ratio was made for a slate, and was found to be negative when perpendicular to the bedding, and 0.35 when parallel to the bedding; whereas a limestone collected at the same locality gave in the same directions 0.43 and 0.45. Such results are evidently worthless; this happens frequently. It is most regrettable because Poisson's ratio is frequently referred to in computations of elasticity.

(3) Deformations - small, linear, reversible. -- The deformations which are measured with the various current extensometers are sufficiently small. On the other hand, they are not always linear; the rocks subjected to pressure present a plastic phase prior to rupture, the importance of which should not be neglected. Theories exist which permit the verification of plastic phenomena in the solution of simple problems. Then one can try to study the deformability under stress conditions close to the real case, assuming a first estimation of the result sought and a solution through successive approximations. However, it is more easily said than done. Finally, in measurements where the deformations are all in the same direction, Mr. Mandel has shown that it is possible to extend the elastic equations to the case of irreversible deformations._/

_/ Mandel, J., Déformations et contraintes dans les milieux ă frottement interne: Travaux, June 1948, p. 297.

D. General heterogeneity

A last cause of error will be mentioned: the mechanical characteristics of rocks vary very rapidly from place to place within a mass. Consequently, it is necessary to study the deformability on the same material that was used for the measurement of deformation, which is not always possible.

II. Direct measurements

A. Generalities

This rapid review, although very incomplete, shows the significance of a direct measurement of stresses.

B. Restoration under press method

The first idea was to cut a block of rock previously provided with extensometers and to restore the stresses under a press in the laboratory. The principle is simple but the realization is difficult: the block has to be cut off from the mass, to be sent to the laboratory, inevitably to be cut again in order to adapt it to the press, and these operations have to be performed without creating any fissures and without touching the extensometers. Any engineer who has had to deal with providing rock samples to a laboratory knows that these operations are not without risk.

Moreover, because the expansion occurs in two directions, the phenomenon calls for the study of two parameters, which, in principle, necessitates two equations of deformation.

C. Flat jack method

a) Description of the test (fig. 1).

The state of deformation of the rock having been registered by means of vibrating strings, which are reliable even in a wet medium, a rectangular slot 2 to 3 cm high is made in a plane of principal stress. A flat jack, Freyssinet type, with the same dimensions as the slot, is inserted into it and sealed. The state of initial deformation is then restored. The necessary pressure, independently from any elastic hypothesis, measures the principal stress of the rock in place, inasmuch as the thickness of the jack in negligible in relation to its length.

Only two hypotheses remain to be made:

First hypothesis - The pressure transmitted by the flat jack can be substituted for the field of stresses transmitted by the rock.

Second hypothesis - A well-defined state of stresses corresponds to a state of deformation of the rock.

A discussion of these two hypotheses follows.

b) Hypothesis of uniform pressure.

The flat jack can only transmit a uniform pressure, with the exception of the discontinuity due to the boundary zone of the jack edges. The test will be correct only if the field of stresses was itself uniform and normal to the expansion plane, which requires a cut in a plane of principal stress sufficiently shallow to assure that the stress is constant in depth.

Besides, if wanted, the direction of the principal deformations can be determined by a preliminary test. For that purpose, three extensometers are set in various orientations on the wall, and the complete expansion of the rock is brought about by means of an unbroken circular cut which surrounds the extensometers, and which is deep enough to give the deformations in three directions. The strain ellipse can then be drawn, consequently the principal directions. Another method, used by Mr. Tincelin, consists simply in making a hole and marking the symmetries of the deformation. In an elastic mass, the principal directions of stresses and deformations coincide. In an anisotropic mass, which happens is not too well known. Some instances would require a study that the authors have not approached, particularly if the principal directions of deformations do not coincide with the stress directions which have previously been determined, for example, according to considerations of symmetry.

The variation of stress in depth in the zone of action of the flat jack is shown by means of pins with double vibrating string. The measurement of the pin rotations may present correction of the results.

c) Value of the criterion of deformation.

Let us now consider the criterion of deformation which will be used to determine the return to the initial stress field. One of the difficulties to be foreseen is that caused by rock creep, a phenomenon which occurs quite frequently in deep galleries. A curve of deformability of a material with creep will be considered (fig. 2). Beyond the pressure P_A, which corresponds to point A of the curve (limit of elastic deformations), the curve deviates, the deformability increases. Let B be the point corresponding to the natural state in place at the beginning of the test (pressure P_B, deformation D_B). The opening of the slot causes an expansion and the line drops to C. When the flat jack is put into operation, the state of deformation D_B, is obtained for a pressure P_E, which may be considerably lower than pressure P_B, wherefrom a very significant error may be introduced if the test is not interpreted correctly. It is thought that this difficulty may be eliminated by continuing to increase the pressure in the jack until point F is reached, which corresponds to a sudden variation of the deformability.. The sought pressure P_B is there in effect equal to the pressure P_F. If P_F is slightly different from P_B, it will be in excess. Consequently, one will remain on the safe side.

This method is not suitable when the natural state corresponds to a point of the rectilinear section OA. To check it, it is sufficient to produce a new expansion such as GH. If $D_H > D_C$, the creep case is found; if $D_H = D_C$ the elastic state is met. The sensitivity of the method is connected with the expansion obtained P_B -- P_C which is related to the dimensions of the slit.

It is thought that in this regard the in place tests will be the best basis for judgement in defining the real importance of this phenomenon.

D. Control of the method: laboratory test.

a) Generalities.

The test reported below made it possible to verify the operating conditions of the equipment and to control the results given by the test in place.

b) Mode of operation.

It was impossible, for economic reasons, to carry out in the laboratory the test as previously described. It would have been necessary to drill in a mass of large dimensions the seating for the jack and to exert high pressures on this mass. The ideal would have been to have several materials available, showing various characteristics of deformability. Very great expense would have been involved. Consequently, the writers merely studied the extent to which the presence of a flat jack sealed in a concrete mass and subjected to a pressure equal to that applied to the rest of the mass modified the state of deformation of the mass in its immediate vicinity.

To that effect, the test was organized as follows:

A concrete mass had been cast on the floor of the large press of the laboratory for previous tests. These tests had made it possible to determine the elastic properties of the mass by various methods. This slab has served, without any modification, for the first part of the test. For the second part, a horizontal indentation of 40 x 23 cm and 3 cm high was made in the free edge of the slab. The flat jack was cast into it in a quick-setting mortar bath, the upper surface being made even with the initial level of the mass.

This rectangular flat jack was built at the authors' request by the "Société Technique pour l'Utilisation de la Précontrainte". Because right angles produce excessive pressures, curvatures of 35 mm. exterior radius were subtituted. The rest of the construction is strictly classical (fig. 3).

The pressure was provided by a hydraulic pump.

A vibrating string was sealed in the mass in the axis of the press and slightly set back in relation to the vertical boundary plane of the mass. The diagram shows its exact position and the general arrangement of the equipment (fig. 4).

The 2,000-ton /metric/ jack, resting on the mass by means of rigid steel chock of 1 m^2 section, made it possible to produce in the flat jack zone a compression field of the order of 200 kg/cm^2.

c) Principle of the test.

It was attempted to obtain a uniform pressure under the chock. To this end, two arrangements were tried, one consisting of setting the chock on a bed of fine sand, the other of intercalating a wood flooring 2 cm thick. This second method proved to be much more effective than the first one; however, considering the crushing undergone by the wood, it is probable that its effectiveness is not perfect in the field of strong pressures.

In the first part of the test, the pressure was applied to the undisturbed mass and the deformations of the string were recorded as a function of the mean pressure.

In the second part, the deformability was studied in terms of the two variables: the mean general pressure and the pressure in the flat jack.

When the pressure in the flat jack is equal to the mean pressure applied on the surface of the chock, the two tests should give the same deformation for the same mean pressure.

d) Results of the test

(1) Behavior of the material. - The flat jack proved to be of very practical use. The double sensitivity pump made it possible to obtain a gradual variation of the pressure; however, the sensitivity of the manometer was insufficient, and that measurement is essential. The test in the field has to be made with a manometer giving a sufficient precision in the range of the pressures to be measured; several manometers could even be used. The flat jack was constructed for a maximum pressure from 110 to 120 kg/cm^2. From 100 kg/cm^2 on, leakages were observed which were impossible to locate; however, they were slight enough that the pressure could be raised to 200 kg/cm^2. The examination of the jack taken away from the sealing at the end of the test, showed an important permanent deformation of the plate on one of its faces, which was caused by the presence of voids in the sealing. Consequently, the setting in the field will have to be watched very closely.

(2) Results. - Diagram no. 5 shows the results obtained.

The sensitivity is extremely high. A variation of pressure of 100 kg/cm^2 in the flat jack gives a deformation of the order of 200×10^{-6}, while a variation of 5×10^{-6} can be estimated without difficulty. It will be seen that the curves (pressure of the flat jack vs. deformation) are in effect straight lines equally inclined with a perfect elastic return, the slight variations are to be ascribed to reading errors of the manometer.

The diagram shows that in the course of this first test the divergences were as follows:

Mean pressure in kg/cm^2	30	40	60	92.5	150
Divergences	+ 17%	+ 10%	0%	-17%	-18%

In fact, the largest part of these divergences is not attributable to the method itself. Indeed, in the zone of pressures lower than 70 kg/cm^2, the strain curve related to the initial mass shows a concavity upward whereas a straight line should be expected instead; the difference may be ascribed to the lack of precision of the manometric measurements in the range of relatively low pressures.

On the other hand, in the range of high pressures, the initial compression field is surely not uniform, the transmission through the wood flooring not being perfect, as mentioned previously. The central zone is consequently at a pressure lower than the mean pressure and the deformation related to the initial mass must be smaller than the deformation obtained when the pressure in the flat jack is equal to the mean pressure; this corresponds to the observations made.

Consequently, this test can be considered as satisfactory.

Conclusion

In conclusion, the flat jack test, although far from being perfect, represents progress in the field of measuring earth pressures from the theoretical viewpoint (because it dispenses with the elastic hypotheses), as well as from the practical viewpoint, considering the adaptability and the ease of use of the necessary equipment, - equipment that is in current use in large civil engineering works.

Anyhow, only the field tests will make it possible to judge the effectiveness of this method and to direct the research toward improvements.

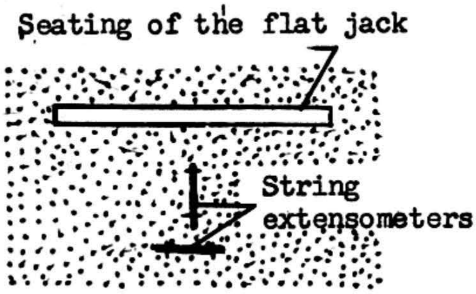


Fig. 1 Sketch of the test principle

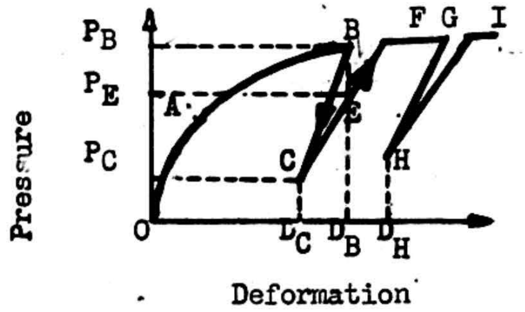


Fig. 2. Stress-strain curve

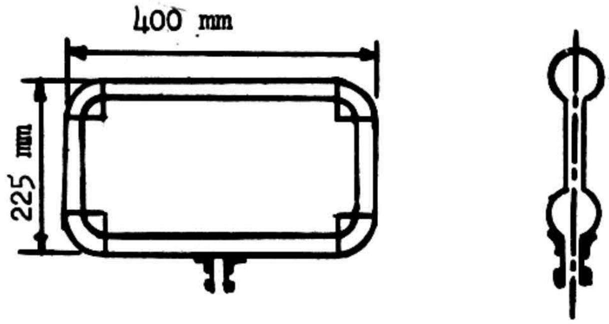
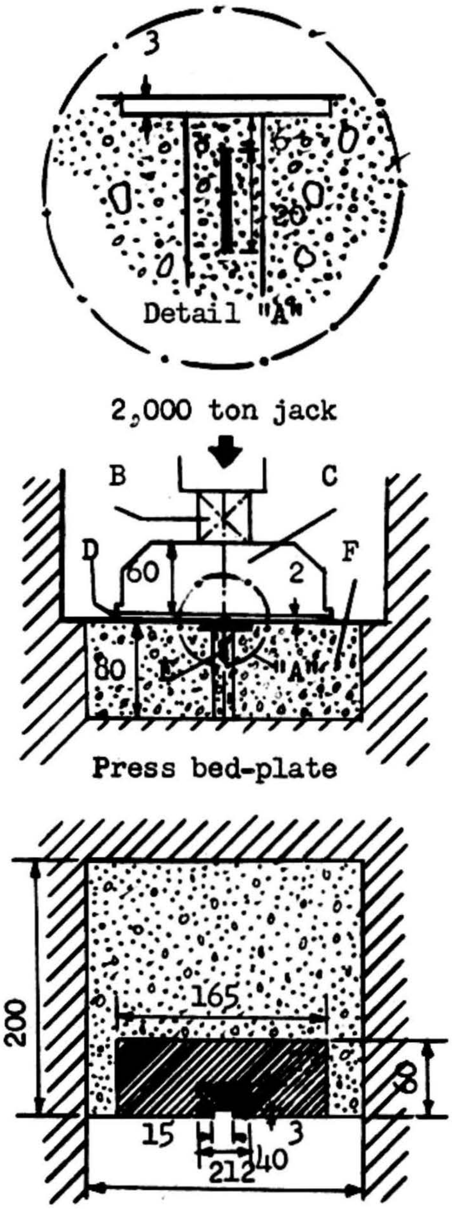


Fig. 3. Sketch of the flat jack



B. **Steel chock** C. **Rigid plate**
D. **Wood flooring** **E.** **Vibrating string**
F. Concrete mass

Fig. 4. General installation of the **flat jack test**