OBSERVATIONS ON THE PROCEDURES AND ON THE INTERPRETATION OF THE PLATE BEARING TEST

QUELQUES OBSERVATIONS SUR LES MÉTHODES D'EFFECTUATION ET SUR LES CRITÈRES D'INTERPRÉTATION DES ESSAIS DE CHARGEMENT SUR PLAQUE

EINIGE ERWÄGUNGEN ÜBER DIE AUSFÜHRUNGSMETHODEN UND AUSLEGUNGSKRITERIEN DER BELASTUNGSVERSUCHE AUF PLATTEN

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SUMMARY - Plate bearing tests are still a rapid and cheap means to assess rock mass deformability. Interpretation of the results, however, is complicated by the presence of loose zone having a much greater deformability than that of the undisturbed rock mass. The problem was tackled by means of an axissymmetrical finite-element model, and it was possible among other things, to establish the great influence exerted by even a thin loose zone of rock on the evaluation of the rock mass deformability. Based on this study, a method for interpretation of the test results was developed, whereby it is possible to obtain the deformability of both the loose zone and of the undisturbed rock through surface measurements of displacement of points located at different distances from the loading plate, and on the walls of a borehole drilled at the center of the loading area, if desirable. For this purpose, use it also made of seismic refraction measurements and seismic logging. The paper describes the equipment developed for the tests and provides a few results of a first measurements campaign.

RÉSUMÉ - L'interprétation des résultats des essais de chargement sur plaque est compliqué par la présence, en surface, d'une bande relâchée de matériel, ayant une déformabilité beaucoup plus grande que celle de l'amas rocheux intact. Le problème a été attaqué du point de vue théorique moyennant un modèle axe-symétrique composé d'éléments finis; l'étude a permis de faire ressortir l'influence élevée qui est exerxée par la presence d'une bande, même ayant une épaisseur mince, de matériel relâché. En se fondant sur cette étude l'on a mis au point un schéma d'effectuation des mesures qui prévoit le relèvement des déplacements en surface dans des points situés à différentes distance de la plaque de chargement (et, éventuellement, dans des points, aussi, situés sur la paroi d'un trou de forage au dessous du centre de la plaque elle même);en utilisant aussi les mesures de réfraction sismique en surface et de carotage sonique en trou il est possible ainsi d'obtenir soit les caractéristiques de déformabilité de la region relâchée soit les caractéristiques de l'amas rocheux intact.

ZUSAMMENFASSUNG - Die Plattenbelastungsversuche sind noch heute eine schnelle und ökonomische Methode für die Bewertung der Verformbarkeit der Gesteinsmassen. Die Ergebnisauswertung dieser Versuche wird jedoch durch das Erscheinen einer lockeren Materialschicht von unterschiedlicher Stärke an der Oberfläche erschwert die eine viel grössere Verformbarkeit im Vergleich zu der dahinter liegenden Gesteinsmasse hat. Das Problem wurde vom theoretischen Gesichtspunkt aus behandelt, und zwar mittels eines axisymmetrischen Modells mit der Methode der Finiten Elemente. Das studium hat under anderem ermöglicht, den grossen Einfluss hervorzuheben, der sich durch das Auftreten auch einer beschränkt starken Schicht lockeren Materials ergibt. Anhand dieses Studiums ist ein Schema der Messungsausführungen festgesetzt worden, welches die Aufnahme der Verschiebungen an der Oberfläche an Punkten verschiender Abstände von der Belastungsplatte (und eventuell auch an Punkten an der Bohrlochwand unterhalb der Mitte der Platte) vorsieht. Wenn man auch die Refraktion-Seismikmessungen an der Oberfläche und die Schallkernbohrungsmessungen anwendet, so ist es möglich, einerseits die Verformbarkeitseigenschaften der lockeren Zone und andererseits die der dahinter liegenden Gesteinsaufspeicherungen festzustellen.

1. FOREWORD

A "loose" zone of rock, that is, rock having distinctly inferior mechanical characteristics to those of "undisturbed" rock, forms from any underground or open-pit excavation in rock masses. This "loose" zone affects the results of the in-situ test that are carried out for the determination of the deformability of rock masses. However, the question of assessing the magnitude of this effect and its pratical significance has not been solved satisfactively yet. ENEL has always been interested in developing the knowledge of rock mechanics, and a few years ago it launched a vast research program, aimed partly at general matters and partly at applications to construction of new power-projects. The lines along which the program is proceeding were described in a recent paper (Dolcetta, 1972), to which the reader is referred also for the bibliography. Within the framework of this program, a study was also started on rock deformability measurements, which included a special investigation on the influence of a "loose" zone such as mentioned above. This paper summarizes the results obtained to date with reference only to plate bearing tests. The determination of the elasticity modulus of rock by means of this method requires relativity simple, sturdy equipment, which is generally easily handled. In addition, the test can be performed rather quickly and at a relatively low cost. Notwithstanding these advantages, the plate bearing test equipment and procedure have not yet been standardized, though the test is quite commonly adopted (Stagg. 1968). From the standpoint of the validity of the results, the factors that appear to be determinant are the bearing plane preparation, the loading method, and the sensitity and precision of the settlement recorders. As concerns the interpretation of the results, the method normally used is Boussinesq's theory for loads concentrated or spread over an elastic half-space, but this interpretation gives rise to a number of uncertainties, just as in some of the other tests. In tackling the matter of taking into account the presence of a superficial "loose" zone (unhomogeneous medium) in rock masses, we have therefore also performed a critical survey of some of the test procedures and equipment, in order to prevent any improvements in the theory from being obscured by faulty techniques (Benson, et al, 1966)

2. THEORETICAL STUDY OF STRATIFIED ROCK BEHAVIOR

The problem of determining the state of deformation of stratified rock was analyzed by means of photoelastic models and was solved analyti cally only for a few simple cases (Maury, 1970). In our study we have used the finite-element calculation method, which is known to be very flexible, and allows the use of less rigid and simplified theoretical schemes. At this stage, we considered the rock to be inhomogeneous but still isotropic and linearly elastic. However, the study can be extended as soon as sufficiently detailed information is available on the anisotropy and non-linearity of rock masses (Oberti et al, 1970; Martino e Ribacchi, 1972). The calculation in this study were performed by the Geotechnical Service of the National Studies and Design Center of ENEL, by means of a finite element computer code, AXSY, which is capable of solving linear-elasticity problems in axial symmetry conditions. A mesh of 790 linear-triangule elements and 435 nodis was developed. We considered the rock to be made up of only two constant-modulus layers (Fig. 1) even though it is to be expected that modulus will continually increase within the "loose" zone starting from very low values. However, the study could be easily extended to more realistic schemes.

A preliminary investigation was conducted for the purpose of checking the validity of some hy potesis and assumptions. The mesh validity check gave quite satisfactory results with known situation. The preliminary study also confirmed that the results obtained with a plate bearing test are largely dependent on the

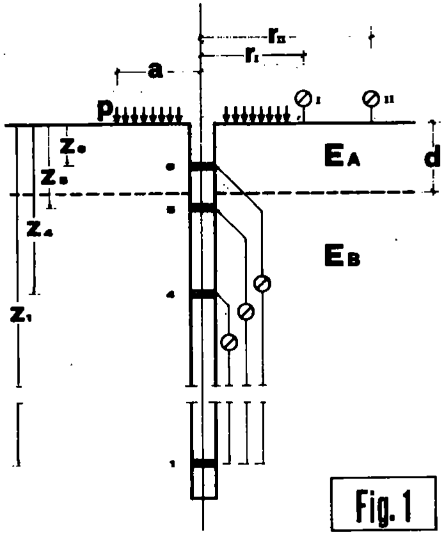

Fig. 1

plate-to-rock rigidity ratio and on the presence or less of a block of concrete or other material. To avoi uncertainties in the interpretation of the test results it is necessary to adopt loading systems that will simulate the theoretical interpretation models available today as faitfully as possible; for obvious technolical reasons the choice fell on the perfectly flexible plate model that can be realized by means of flat jacks resting directly on the loading surface. This preliminary study afforded, among other things, a confermation that the presence of a relatively large hole (0. 15 times the plate dimension in diameter) doe not substantially affect the state of deformation, expecially when the reduction in total load due to the hole is taken into account. Based on these results, a detailed study was performed on the influence on the displacement of the individual points of the half-space exerted by each of the three essential parameters characterizing the model, that is, the modulus E_A of the loose zone, its thickness d, and the modulus E_B of the undisturbed rock. As Poisson's coefficien affects settlement very slightly (Stagg, 1968), it was assumed constant (ν =0, 2). Fig. 2 shows an adimensional representation of the settlement W in the direction of the applied load, calculated for a point a the surface, as a function of the ratios between the two rock moduli and between the thickness of the loose zone and plate radius. The figure show among other things that a small loose zone thickness causes an appreciable increase in settlement even if it is no very deformable.

Similar charts can be built for any other significant point, and the analysis can be repeated for other situations on the same mesh at very little cost. In determing the elastic moduli of the indisturbed and

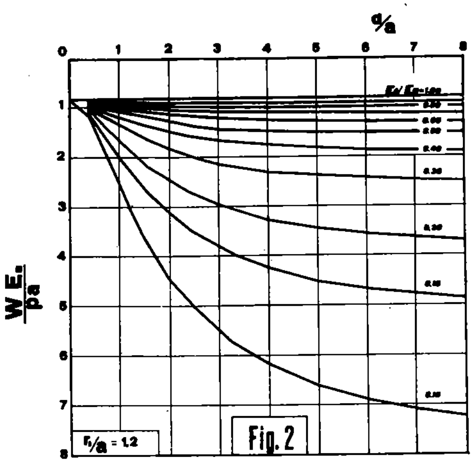

Fig. 2

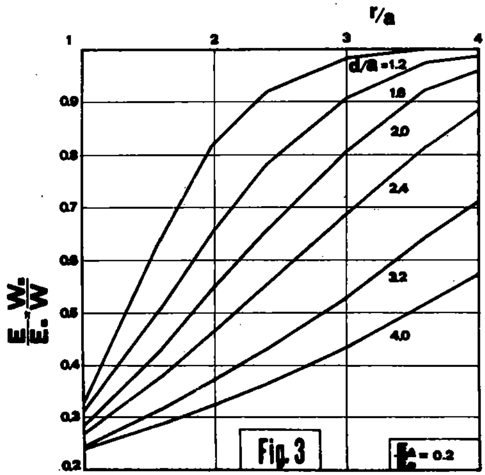

Fig. 3

›se rock masses from the settlements measured in ·situ tests, consideration was given to the fact that ttlement of each point is affected differently by the esence of the loose zone. Fig.3 shows, as an exam- ;, how the settlement W at the surface varies in spect of the corrisponding settlement W_B of a mogeneous rock having an elasticity modulus E_B, as unction of the distance from the plate center for ferent thickness of the loose zone and for a constant /E_B ratio. In the figure, E represents the "apparent" ›dulus of the soil, for the point where settlement W s measured, computed, on the basis of Boussinesq's ›ory.

FIRST APPROXIMATION CRITERION FOR INTER-PRETATION OF THE PLATE BEARING TESTS IN A TWO-LAYER MEDIUM

developing a first approximation criterion we have ed to avoid complicating the test. We assumed that ly superficial settlements were measured, that the ·esses were of the usual order of magnitude (10-15 ʌ/m^2) and that the settlements, measured with the ual dial gages or transducers, were never very eat. Theoretically, it would suffice to measure ttlement at three distinct points of the half- space der the plate to derive the unknowns of the problem, mely, the moduli E_A and E_B, and the thickness d. e to the inevitable random scattering of the readings d to the difficulty of measuring small settlements, ; different influence of the two-layer rock deforma- ity, as compared with homogeneous rock, on the ttlement of two adjacent points is hardly appreciable. practice, it is hard to get meaningful readings at ›re than two points at the surface. A rough estima- n of the thickness of the loose zone can be obtained ›ugh the micro-seismic refraction curves(geophones ;ated 0.5-2m apart) taken along a line passing ·ough the center of the loaded area. It is known that the velocity of longitudinal elastic wave propagation in a rock mass is related to the deformability of the rock, and that by using appropiate instrument for the refraction tests it is possible to establish the thicknesses of the layers in stratified rock when the propagation velocity increases with depth. Today, by using closely special geophones it is also possible to measure thicknesses of a few tens of centimeters having a propagation velocity of 1-2Km/s. over a background having a velocity of a few Km/s. Based on ENEL's (Bertacchi and Sampaolo, 1970) and ISMES's wide experience with seismic methods for characterization of rock masses, it was seemed justified to try to evalute the thickness of the loose zone by seismic refraction measurements with standard instruments and techniques that had been appropiately adapted (Istituto Sperimentale Modelli e Strutture, 1973). In such a case, the problem is solved by the diagrams in Figs. 4 and 5. Indeed, settlements W_I and W_{II} allow "apparent" moduli E_I and E_{II} to be calculated through Boussinesq's theory. Once the d/a and E_I/E_{II} ratios are known, from the diagram in Fig. 4 we can determine E_A/E_B. When the latter ratio is known, we can obtain the value of E_I/E_B from the diagram in Fig. 5 for the same d/a ratio. And since E_I is known, we can first calculate E_B and then E_A .

4. EXPERIMENTAL VERIFICATION CAMPAIGN AND FUTURE DEVELOPMENTS.

The validity of the method described in the prceding Section was checked for the interpretation of the plate bearing tests performed within the framework of the investigation carried out for the excavation of the Pelos underground power station in the eastern Alps. The rock which is to be excavated is made of alternations of statified limestones and marly limestones. The drift (about 2,5 m in diameter) was bored by

TABLE 1

	N°	E_I GN/m²	E_{II} GN/m²	d m	E_A GN/m²	E_B GN/m²	V_A km/s	V_B km/s
Normal to bedding	1	9.8	10.3	0.60	8.3	12.0	4.5	5.8
	2	4.2	4.0	1.15	4.1	-	4.5	5.6
	3	13.6	13.2	0.00	-	13.3	-	5.8
	4	2.4	1.9	0.20	2.2	-	3.2	5.6
	5	1.8	1.5	0.55	1.7	-	3.2	5.8
	6	3.1	3.7	0.15	3.4	-	5.1	5.6
	7	7.9	8.1	0.45	7.2	8.4	5.1	5.6
	8	7.8	8.5	0.35	6.5	9.2	5.1	5.8
	9	7.3	8.1	0.10	3.3	8.1	3.7	5.8
	10	2.0	1.9	0.20	2.0	-	3.7	5.8
Parallel to bedding	11	14.3	12.8	0.00	-	13.8	-	5.2
	12	11.5	12.7	0.50	9.8	14.5	4.3	5.2
	13	5.2	5.1	0.65	5.2	-	4.3	5.2
	14	7.6	9.2	0.10	1.9	9.3	4.3	5.2
	15	5.7	8.3	1.20	7.0	-	4.3	5.2
	16	8.3	5.8	0.45	7.0	-	4.3	5.3
	17	16.9	17.9	0.50	15.5	19.3	4.3	5.3
	18	8.6	8.6	0.45	8.6	-	4.3	5.3
	19	6.5	8.5	0.40	4.3	10.5	4.3	5.3
	20	5.1	6.2	0.75	4.1	9.7	4.3	5.3

controlled blasting. Micro-seismic refraction profiles were taken in the drift, and twenty plate bearing tests were performed, with the load applied both perpendicularly and parallel to the stratification. All these were performed by ISMES. The loading areas were flattened by means of a little pneumatic hammer and smoothed with a thin layer of mortar. The equipment used in the test was developed by ISMES with the cooperation of the Hydraulic and Structural Research Center of ENEL's Studies and Research Direction and consisted of a central tube lodged between the walls of drift and connected, by large adjustment screws, to two plates under which the flat jacks in welded plate are located. The jacks have a diameter of 500 mm and are provided with rounded and enlarged rims. Shaped wooden shims are glued to both faces. The jacks are concurrently set in operation from a small hydraulic pumping unit, and were laboratory tested up to a maximum pressure of about 20 MN/m². This loading equipment which can be used in tunnels up to 4 m i diameter, is mounted on a dolly and can be rotated around two orthogonal axes. Two hydraulic jacks at the sides of the dolly allow the height of the central tube to be adjusted. In this manner, the load can promptly be centered and the equipment can easily b moved from one measurement point to another.

In the Pelos investigation, the maximum test pressu (10 MN/m²) was reached through a process of repeat loading and unloading cycles at two intermediate pressure steps (4 and 7 MN/m²). The average value (calculated from the harmonic mean of the moduli) an the variation coefficient of the elastic modulus were computed cycle by cycle, for each measurement point.' painstaking analysis proved extremely useful as it provided unbiased criteria for the detection of abnormal values caused by temporary instrument malfunctioning. The modulus obtained for the various loading and unloading cycles were averaged separate for the values read on gages located near the plate a those read on gages farther away, not taking to account the first - loading curve("vergin" deformati curve). Table I shows the values of the "apparent" moduli thus obtained, of the thickness of the loose z assessed by seismic refraction means, of the modu E_A and E_B derived from the diagrams in figs. 4 and with the procedures described in the preceding sectic and of the average seismic velocities of the loose zo and substratum. Fig. 6 correlates all the elastic moduli with the corresponding squared velocities, wi reference only to the loading tests perpendicular t the statification.

In studying the results, the first thing to be borne in mind is that, since the medium is stratified, the seismic velocities obtained have a different significance depending on whether the geophones were located at the sides of the drift. The velocities indicated in the lower half of Table I appear, at a firs glance, to be less meaningful than those in the uppe half. On the other hand, when the velocities in the loose zone and substratum do not differ much (indicating nearly the same degree of fracturing), al the precision of the evaluation of the loose zone thickness decreases. This may explain some of the grea differences in the results given in Table I, the most evident being those relates to tests Nos.6, 13, 17. At a rate, the first approximation method developed for interpretation of the plate bearing tests is capable o providing a satisfactory indication of the average elasticity modulus of an undisturbed rock mass. Fig also illustrates further possible areas opened by suc an interpretation of the plate bearing tests; indeed, t possibility of better correlating deformability measu statically with the propagation velocities of longitudinal waves is extremely important for the complex problem of rock mass characterization (Kujundzic a Grujic, 1966)

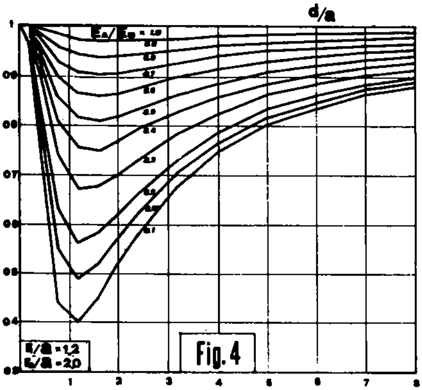

Fig.4

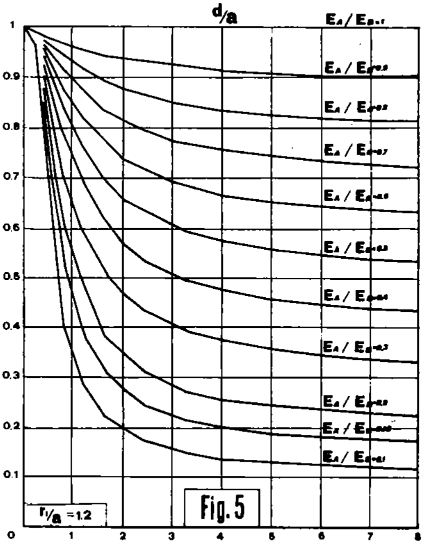

Fig.5

The moduli of a two-layer medium could indoubtely be assessed more easily if we could also find out the relative displacements of the points on the walls of a borehole drilled at the center of, and perpendicular to the loading area. On the basis of diagrams and procedures similar to those in Figs. 4 and 5 it would be possible not only to obtain independent estimates of E_A and E_B, but also to verify the validity of the estimate of the loose zone thickness obtained through seismic refraction methods. More specifically, it would be possible to produce, with the data already available, different diagrams that would allow the parameters E_A, E_B and d to be calculated directly from the "apparent" moduli derived from measured displacements. Drilling of a borehole at the center of the loading area and the installation of instruments are indoubtely complications in the performance of the plate bearing test. However, in the course of geomechanical investigations, boreholes are normally drilled for several purposes (sampling, for instance); some of them could easily be located in the loading test areas without unduty increasing costs. A borehole at the center of the loading area also allow the local state of fracturing to be determined in detail, especially through sonic logging. The aggregate information obtainable with the boreholes could be useful also to establish more justified relations between the quality indexes used for rock mass classification and the deformability of rock masses. Therefore, it was deemed convenient to develope a test method and test equipment to do this. The new equipment (Fig. 7), developed by ISMES with the cooperation of the Hydraulic and Structural Research Center of ENEL's Studies and Research Direction, includes devices that can be fixed at different depths in the borehole by means of six expansion anchors, and are connected by means of metal rods to displacement transducers mounted on a support that is rigidly atthached to the borehole mounth. A flat anular jack transmits the load to the rock and allows passage of the instruments. The anchors (Fig. 8) consist of two brass disks connected by a central screw and three wedges. By turning the screw, the three wedges are forced to adhere to the wall of the borehole at the desidered depth. The anchors are positioned by means of a locking key, which also allows their recovery after the test. The equipment is designed for boreholes 75mm in diameter and 6 m deep.

The displacement of each anchor relative to the deepest one taken as fixed, is measured by mean of weatherproof displacement transducers of the variable-inductance type, with a range of 10 mm and a sensitivity of 1 μ ,. connected to an automatic data recorder. The above described equipment was successfully used recently in an in-situ investigation campaign. Processing of the results is still under way because in order to interpret them corretly it has been necessary to trim up statistical methods.

A first conclusion that can be drawn from our work so far is that the modifications we introduced in the plate bearing test technique and interpretation

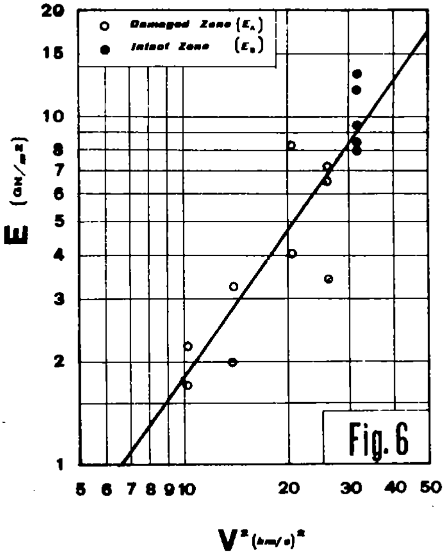

Fig. 6

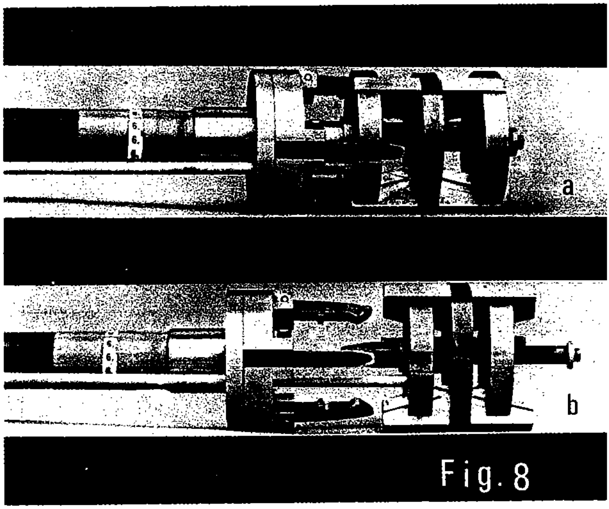

Fig. 8

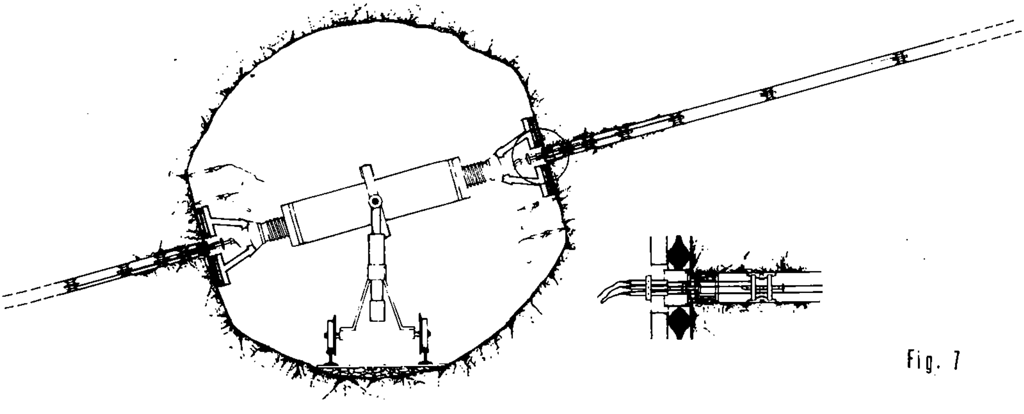

Fig. 7

criteria are satisfactory: without undue complications it has been found possible to take into account the effect of the superficial loose layer.

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