SUB-SECTION Vc

EARTH PRESSURE AGAINST UNDERGROUND CONSTRUCTIONS

V c 2

EARTH PRESSURE IN MINING

F.K.Th. van ITERSON

Only in recent times, to be exact, in the congress on rock-pressure held at Treebeek in June 1947, it has been recognised that deep mining in rock and groundwork have the same physical and mathematical basis. By this statement mining became a scientifical engineering proposition. Many of the formulae used in soil mechanics are applicable for expressing earth-pressure in deep mines. Teachers in mining must be versed in soil-mechanics and civil-engineers have the greatest profits by studying the earth-pressure problems underlying the science of mining, which are partly of a more advanced and complicate nature.

The physical explanation of this similarity was unexpected and peculiar. The theory of elasticity to mining, revealed stresses around and in the vicinity of underground workings far in excess of the crushing resistance of the rock. The soil expands to the hollow places and is disrupted so as to form a mass of loose material kept in equilibrium by internal friction. The fracturing of the rock in stead of being an unconveniance is our safeguard and makes mining possible to very great depths.

In stead of withstanding the total depth-pressure, the miner has only to deal with the active pressure exercised on his supports after withdrawing some material and the mathematical treatment shows that by the shape of his excavations the passive earth-pressure is immence but the active-earth-pressure in mining is quite supportable.

In order to show this remarkable fact we shall first give the formulae for the pressure on the timbering of a tunnel of cylindrical shape excaveted through a heap of loose debris of stone or on the lining of a mine-shaft.

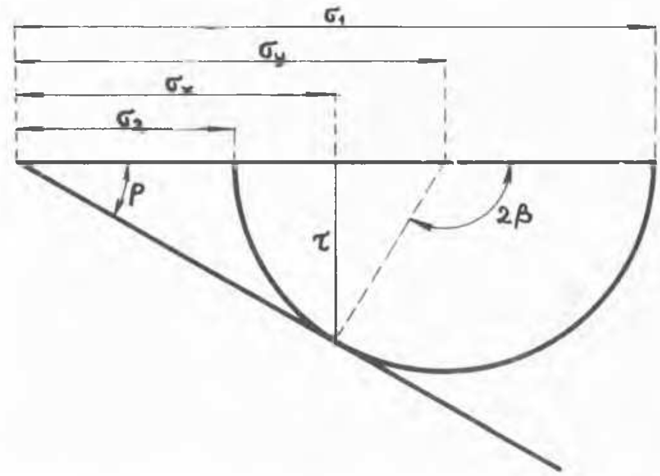
To give a proof of the applicability of our theory on practical problems we shall show the complete agreement of the angle of subsidence by underground workings with that predicted by theory.

Then we shall compute the pressure on pitprops in coalmines and prove by the results of special tests the availibility of the theory of soil mechanics on mining problems.

Also in open-cast mines, we mining engineers made contributions to the theory and practice of soil mechanics and collaboration of efforts in the devellopment of this science would be serviceable to both branches of engineering.

Our only purpose on this occasion is to show that we deal exactly with the same problems as you. It is a mistake that engineers applying and furthering the identical theory don't gather at the same conference. On this end we shall not expose anything new to the reader and may be short.

The rock-pressure at the depth where coalmining takes place in our and the surrounding countries is such that at the spots we make accessible one of the principal stresses becomes nearly zero, the surrounding material expands and breaks into loose material. Hence the physical law from which the pressure on supports and timbering in mines evolves, is that exposed by Coulomb for the equilibrium in the mass of loose material with internal friction, represented by Mohr's circle in figure 1.

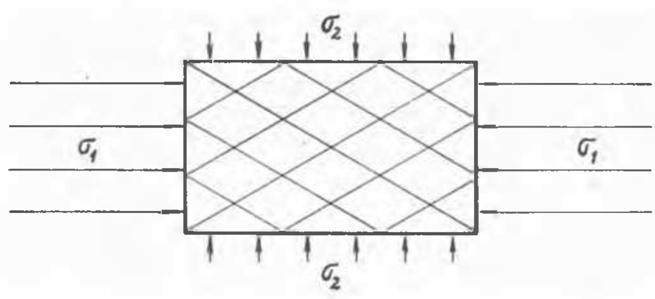


Mohr's circle for the stresses in incoherent masses at respective slipping of the grains.

FIG.1

If we call σ the mean of the two principal stresses in our plane problem at some distance from the hole, $\sigma = \frac{\sigma_1 + \sigma_2}{2}$ then the two principal stresses at the moment of internal gliding are $\sigma_1 = \sigma(1 + \sin\varphi)$ and $\sigma_2 = \sigma(1 - \sin\varphi)$ and their ratio is

$$\sigma_1 : \sigma_2 = (1 + \sin\varphi) : (1 - \sin\varphi)$$



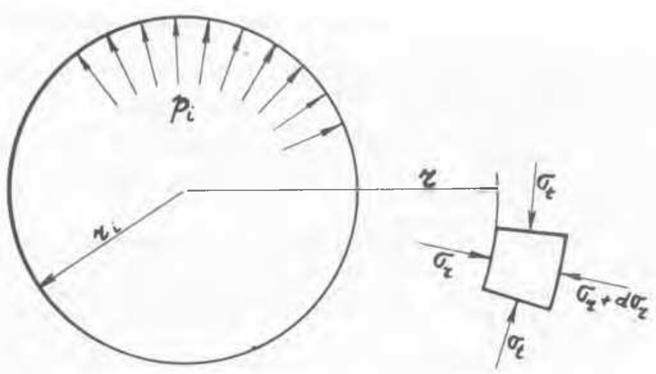
Principal stresses and sliplines in an element of debris of rock.

FIG.2

In figure 2 we indicate the sliplines in an element of the mass of broken rock. As the angle of the natural talus, which is the same of that of internal friction is about 45°. We have the ratio $\sigma_1 : \sigma_2 = 1{,}707 : 0{,}293 = 5{,}83 \backsim 6$ for solving the problems of active and passive rochpressure in deep-mining.

The angle between the sliplines is as in the Rankine-Maurice Lévy-problem $\frac{\pi}{4} + \frac{\varphi}{2} =$
$= 45^\circ + 22\frac{1}{2}^\circ = 67\frac{1}{2}^\circ$

le. We first give the solution for the stress distribution around a mineshaft or a tunnel of circular section, which had been published in 1930. 1)



Notations for the stressdistribution in broken rock round a mine shaft or tunnel of circular section.

FIG.3

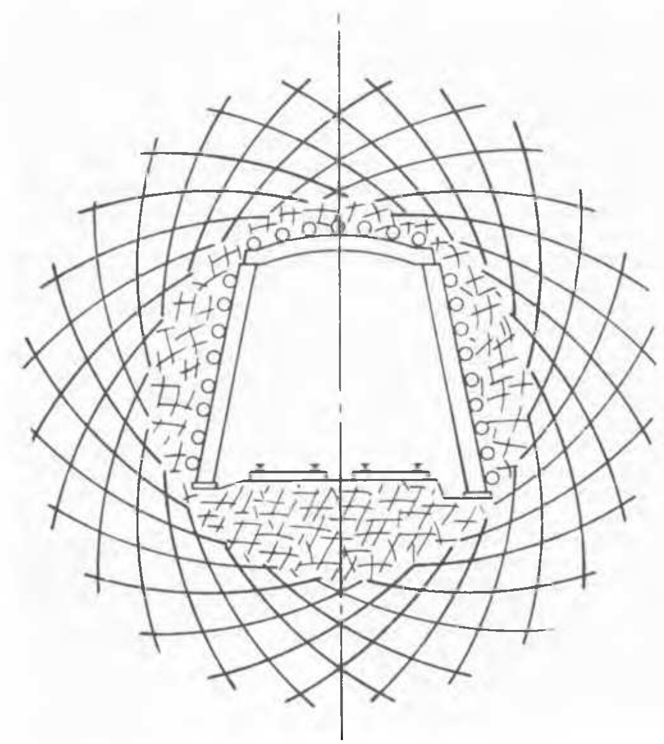
The equilibrium for an element represented in figure 3 gives

$$r\frac{d\sigma_r}{dr} = \sigma_t - \sigma_r \qquad \text{Here} \qquad \sigma_t = \frac{1+\sin\varphi}{1-\sin\varphi}\,\sigma_r$$

And the solution is

$$\sigma_r = \frac{1-\sin\varphi}{1+\sin\varphi}\,\sigma_t = p_i\left(\frac{r}{r_i}\right)^{\frac{2\sin\varphi}{1-\sin\varphi}}$$

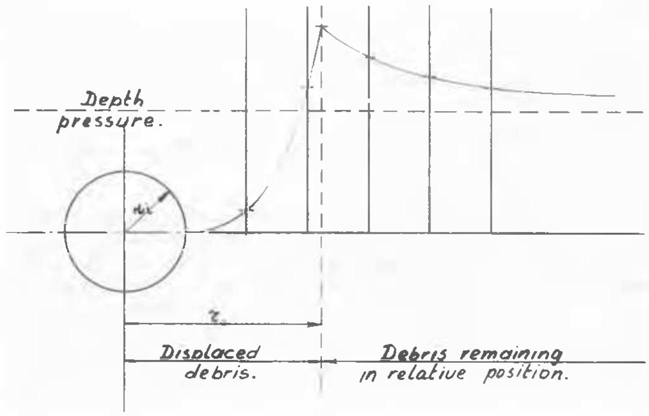
It is essential to remark that the active pressure on the lining may be small and still the internal friction of the debris of rock builds up at a small distance from the cavity a reaction which retains any surrounding pressure. This is represented in figure 4 where the sliplines for the active pressure on the timbering are also indicated.



Section of a timbered main gallery in a mine, surrounded by loose material.

FIG.4

We have calculated the principal pressures in the zone of equilibrium at moving particles. Outside this zone, where no internal displacements occur we have the stress distribution as in thick walled cylinders according to the theory of elasticity as given by Lamé. We can easily calculate where the zone of sliding equilibrium ends and where elastic stresses begin. This radius r_o depends on the internal passive resistance P_i of the timbering but the maximum of the radial stress σ_r grows always to the same altitude as indicated in figure 5 and amounts to about 1.7 times the static depth-pressure in the undisturbed rock. 2)



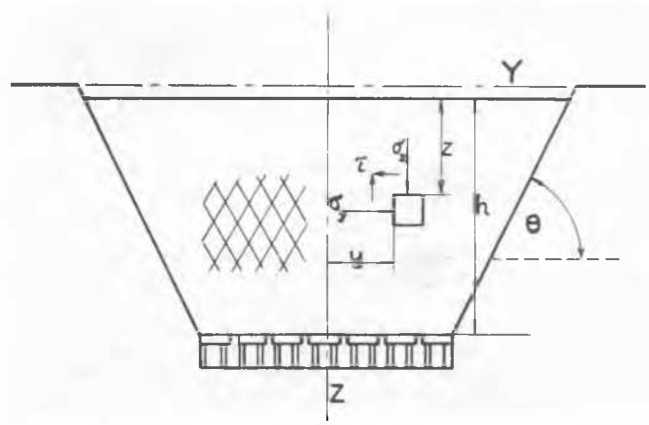
Tangential stress around a shaft or gallery of circular section of loose material.

FIG.5

It is the most remarkable proof of the exactness of our formula that this peak $p_{max.} = 1{,}7 \cdot p_{static.}$ had been exactly ascertained by pressure-boxes in the important research made in England as part of the Falls of Ground Investigations of the safety in Mines Research Board. 3)

2e. Let us now solve the problem sometimes posed to the adepts of soilmechanics to determine the angle of break, the border of subsidence of the surface by undergroundmining.

We calculate the angle Θ in figure 6.



Angle of break Θ in the case of compressible supports or abandoning of the workings.

FIG.6

The wellknown stress distribution is given by Rankine. According to Mohr's circle (figure 1) the plane on which slip occurs makes an angle β with the principal direction.

Now $2\beta = \frac{\pi}{2} + \varphi$

The main principal directions for reason of symmetry are the vertical and the horizontal. The angle of sliding in the loose material inside the subsiding mass as well as the boundery angle θ are equal to β , hence

$$\theta = \frac{\pi}{4} + \frac{\varphi}{2}$$

We mentioned that in debris of rock the angle of internal friction as well as the natural talus is about 45°, thus

$$\theta = 67^\circ\ 30'.$$

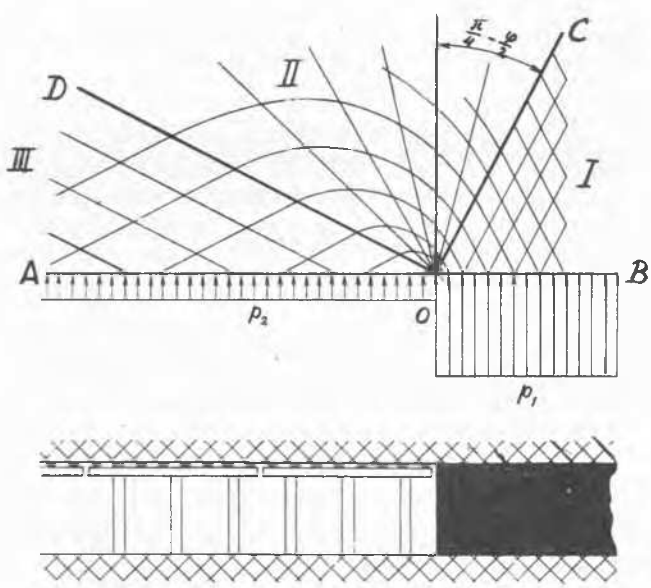
This is exactly the angle determined by Prof. Dr. G.J.A. Grond by carefull investigations in our Statemines. 4)

The vertical pressure in the old workings or goaf tends to the depthpressure $p = \gamma h$ and the horizontal pressure is

$$\frac{1-\sin\varphi}{1+\sin\varphi}\gamma h = 0{,}169\gamma h$$

, where γ is the specific weight and h the depth.

3. The third problem which we shall now solve is to determine the pressure on the coal in the case that the supports near the coalfront are of the sliding type offering equal resistance or are compressed to the maximum charge they can carry when compressed to destruction or pit-props penetrating in roof and floor. This problem is represented in figure 7.



Sliplines in the disrupted rock near the coal-front in longwall workings.

FIG.7

We can obstain from giving the mathematical treatment and mention that we have the reversed picture of the classical problem of soil mechanics, which forms the base of our science, is dealt with in many text-books and was first exposed by Professor L. Prandtl. 5)

One may distinguish three zones in the incoherent disturbed broken rock near the coal-front.

In zone I reigns a vertical pressure p_1 and a horizontal pressure $\frac{1 - \sin\varphi}{1 + \sin\varphi} p_1$. We have here the stress distribution described by Rankine.

This zone is bordered by the slip-plane O – C.

The tangential stress τ_1 and normal stress σ_1 in this plane OC are

$$\sigma_1 = \frac{\cos\varphi}{1+\sin\varphi} \cdot p_1 \quad \text{and} \quad \tau_1 = \frac{\sin\varphi \cos}{1+\sin\varphi} \cdot p_1$$

OC us inclined with the angle $\theta = \frac{\pi}{4} + \frac{\varphi}{2}$ to the surface of the mineral.

Then we enter the zone II, zone COD, in which the sliplines build a set of straight lines through the origine and a set of logarithmic spirals cutting the radials under angles of $\frac{\pi}{2} - \varphi$

In the third zone, indicated as III, there also reigns a Rankine-stress distribution, but here the greatest principal stress is horizontal. The line of delimitation between II and III, OD, is also a common slipline and is perpendicular to OC. The tangential tension τ_2 and normal tension σ_2 on this plane OD are

$$\tau_2 = \frac{\sin\varphi\cos\varphi}{1+\sin\varphi} e^{-\pi \operatorname{tg}\varphi} \cdot p_1$$

$$\sigma_2 = (1-\sin\varphi)\, e^{-\pi \operatorname{tg}\varphi} \cdot p_1$$

and to conclude the mean pression p_2 on the supports

$$p_2 = \frac{1-\sin\varphi}{1+\sin\varphi} e^{-\pi \operatorname{tg}\varphi} \cdot p_1$$

Expressed in figures for the broken rock in deep mining

$$p_2 = \frac{0{,}293}{1{,}707} \times \frac{1}{23{,}14} \quad \text{or} \quad p_1 = 135\, p_2$$

The passive pressure on mine-supports is only a small fraction of that weighing on the coal.

Many more problems of rock-pressure in deep-mining are of the class as those dealt with in soil-mechanics.

REFERENCES

1) F.K.Th. van Iterson. Theorie van het in den grond boren met zware spoeling, enz. "De Ingenieur" 1930 p. M 20 & M 31. Compare: Les Cuvelages par Denoël, Paris 1935 p 52 Handbuch der Physik, vol VI p. 495
Equilibre par tranches planes des solides à la limite d'écoulement par J. Mandel 1942.
Grondmechanica door Keverling Buisman, 2de druk bewerkt door Huizinga p. 193.

2) F.K.Th. van Iterson. La pression du toit sur le charbon près du front dans les exploitations par tailles chassantes. Revue Universelle des Mines Nr. 9;1941.

3) An investigation of the loads on packs at shallow depths by W.H. Evans and H. Henshaw. Transactions of the Institution of Mining Engineers vol. X CVI 1938-1939.

4) Gebirgsbewegungen bei Steinkohlenbergbau by G.J.A. Grond, Inaugural-Dissertation. Geologisches Institut der West-fälischen Wilhelms-Universität zu Münster 1926 p. 30

5) Zeitschrift für Angewandte Mathematik and Mechanik 1921 Nr. 1.

-o-o-o-o-o-o-