WATER BARRIER PILLARS

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ABSTRACT

Water barrier pillars are rock layers of protective effects located between an aquifer and mining opening. Protective effects of rocks: the mechanical stability and hydraulic resistance are discussed. Also, regarding the effects of undermining, different approaches of sizing are presented depending on the protection-properties of rocks and on the type of mining activities. Brief case examples illustrate the methods of sizing and the use of pillars for different geological conditions and mining activities. The Hungarian Mine Safety Regulations and the accepted draft of the new Mine Safety Standards on water barrier pillars are based on the approaches and methods presented.

INTRODUCTION

The water barrier pillars are so called "protective rock layers" between an aquifer and mining opening which are able to eliminate the risk of water inflow or to limit its yield. These protective layers are able to perform their duty only if the rock mass of the pillar has mechanical stability against water pressure and rock material has the necessary hydraulic resistance against water inflows.

In many cases, the use of water barrier pillars is the only way for an effective mine water control. In some other cases the use of water barrier pillars may be one of more possible alternatives or one element of the mine water control system.

The paper discusses /i/ the properties of protective layers /with special regard to the pillars/, /ii/ the sizing of pillars and /iii/ the use of pillars.

1. Protective layers

The main requirements of protective layers are
/i / the mechanical stability and
/ii/ the necessary hydraulic resistance.

In some cases the first requirement represents the critical conditions and in many other cases, the second one is more important. Generally both of them should be investigated.

1.1. The stability of the rock mass of pillars

There is no doubt that a total failure of the rock mass of the pillar absolutely stops its protective effect. For this reason the most traditional sizing approach of water barrier pillars is the stability analysis of the rock mass of the pillars using simplified mechanical models [1/a, 1/b, 2, 6, 11, 19, 20, 26] . /Fig. 1./ These methods, however, neglects the role of faults, fissures and other inhomogeneities of the rock mass of pillars. More sophisticated such as finite element models are also used for analysing the mechanical stability of a fissured rock mass mainly for large earth dams[5]. But the behaviour of faulted, fractured zones cannot be practically modelled even with the most sophisticated models because the mechanical properties of the faulted, fractured zones are mostly unknown.

On the other hand, mining experience has given more reliable information for determining the stability under analogeous conditions.

Schmieder [23] has demonstrated that the mechanical stability of pillars is critical only in cases of very large openings /for this reason the stability of the floor strata of open pits against water pressure may be dangereous/. In many other cases the stability of local anomalies /loosened zones, faults/ is more critical. Consequently, the stability of the rock mass of the protective layers has to be investigated only for very large mining openings /open pit mines/ or for hard fissured rocks of small water conductivity. In the last case a very small water barrier pillar may give the necessary hydraulic resistance, but the rock mass of this small pillar may be unstable.

The analysis of the mechanical stability of the rock mass of pillars are based mostly on mining experience. Simplified mechanical models /Fig. 1./ can be used only under those conditions, where these simplified models are carefully calibrated by a number of empirical data of analogeous conditions. Consequently, these simplified models are only tools for better use of the experience gamed under analogeous conditions.

More sophisticated models, such as finite element techniques may also be used, but the model has to be fitted to the empirical data very carefully using special measurements of rock displacements and stresses along the boundary and even inside the rocks.

1.2. The permanent hydraulic resistance of pillars

The mechanical stability of the rocks of pillars is only one of the necessary requirements. In most of the cases, fissures, faulted zones may be enlarged /a so-called piping process may occure due to the mechanical and/or chemical interactions between the rock and the water/ [8, 15, 27]. Under conditions of piping the pillar cannot limit the water inflow, even if the rock mass of the pillar is in a state of equilibrium. Consequently, the hydraulic resistance of the rocks of pillars should also be investigated very carefully, taking into account the changing hydraulic resistance due to the effect of water and mining activities as well.

Concerning the stability of hydraulic resistance /or conductivity/ of protective layers the main types of cases are as follows:

a./ Hard, homogeneous rocks of quasi constant and limited permeability will stay protective layers for almost all conditions. These layers are called: "protective layers of constant permeability". The piping process of these layers can be eliminated, but the fractured zones due to the effects of the mining activity must not be taken into account as protective layers. Faulted zones of these hard rocks will be discussed later.

b./ Soft impermeable layers /e.g. clays, clay breccias/ can be taken into account as protective layers only in special cases, because uncontrollable piping process may occur due to the chemical and/or mechanical effects of water. The protective effect of the soft water layers can be taken into account only in cases when the risk of the start of water seepage is excluded.

c./ Loose granular layers /e.g. sands/ can be taken into account as protective layers only under those special conditions, when the risk of the occurrence of piping process can be eliminated on a very high level of confidence.

d./ Solid, fissured, faulted rocks, /fissure reservoirs where the faulted zones and/or fissures are filled with loose or soft materials/ can be taken into account as protective layers only in two special cases:

Number one: there is no waterflow through fissures /see case b./

Number two: Because of the small sizes of fissures and/or faults the permeability of the rock is limited even in the case, when the soft or loose mass from the fissures is mostly removed because of the dynamic effect of water movement. In the last case, the rock layers are called "protective layers of limited water conductivity".

According to the above types the protective effect of layers strongly depends on conditions of piping process:

- for cases b./ c./ and d./1 the risk of the start of piping;
- for case d./2 the final condition of piping /the final sizes of fissures/ have to be determined and
- for case a./ the eligibility of the piping process has to be carefully demonstrated.

For these reasons, the piping process and its two key questions:
- the risk of start of piping and
- the final condition /the final hydraulic resistance/

will be described next.

1.2.1. Brief discussion on the piping process

Concerning the piping process, two main types of rocks have to be pointed out:

Type No. 1. includes loose porous-media soils. /These may be quasi homogenous soil masses or fissured, faulted zones filled with loose granular rock material/.

Type No. 2. includes soft waterproof soils. /These also may be quasi homogenous soil masses, tectonically faulted fractured ones - clay breccia - or fissures in hard rocks filled with soft material/.

1.2.1.1 The risk of the start of piping

The piping process in loose porous media has been studied [27, 20, 17, 18, etc.] with special regard to stabilities of slopes, earth dams and to the performance of filter wells in sands.

During seepage the mechanical interaction between the porous media and the water can be expressed as a seepage pressure /p_s/ in function of the actual hydraulic gradient /I_a/ [27]

$$p_s = \gamma I_a \qquad /1/$$

which is one of the components of the rock stress conditions.

If the other components can be considered as constant, piping may start if the actual gradient /I_a/ exceeds a critical value /I_{crit}/.

$$I_a > I_{crit} \quad \text{or} \quad \frac{I_a}{I_{crit}} > 1 \qquad /2/ \quad /3/$$

Because of rock mass heterogeneity, I_a and I_{crit} can be considered as random variables, consequently their ratio is also random characterized by a probability function as Harr and Sipher [8] showed /Fig. 2./. It has been also demonstrated that in many other cases the other stress components of the equilibrium cannot be neglected [12]. Consequently, empirical distributions of the risk of piping given by mining experience, can be used for prediction only under analogeous condition. The analogy of rock properties, rock stress conditions and the dynamic conditions of seepage are all required. Computer simulation methods may be useful for determining the effect of different parameters on the value of the critical hydraulic gradient I_{crit} [8]. These tools may help us to decide whether the empirical data of a given case can be used for predicting the risk of piping in an other case.

The piping process in soft impermeable soils is more complicated phenomenon which is generally unknown.

In the practice of surface water management the piping process is deeply studied, mostly with special regard to enlarging of original soil channels [25]. It has been determined that the enlarging of the original channels /the so-called piping process/ occurs due to the deflocculation effect and it does not depend strongly on the actual hydraulic gradient.

The empirical data of thousands of Hungarian mine water inrushes from aquifers through protective layers /tectonically faulted soft clays, marls, etc./ demonstrate a strong dependence between the risk of the piping and the actual value of hydraulic gradient, although the effect of the deflocculation has never been detected because of the high free Ca^{++} ion content of the protective layers. Fig. 3. presents the risk of the start of piping /f_s/ according to the empirical data of Hungarian coalfields. The same figure presents the empirical distributions of the critical hydraulic gradient /$P(I)$/ as a derivate of the risk-curve.

According to the actual prescription of the Hungarian mine safety legislation [21], this empirical distribution of the critical hydraulic gradient is used for predicting the water hazard and for sizing water barrier pillars under analogeous conditions [14].

In underground reservoir engineering practice a sudden change of the hydraulic resistance of rocks can be attributed also to the hydrofracturing effect. An empirical value of the hydraulic gradient of hydrofracturing is also mentioned by some authors. Consequently, the risk of the starts of piping can be expressed using an empirical distribution of a critical value of the hydraulic gradient even for soft impermeable rocks.

According to mining experience and experiments [12, 13, 14, 15] the critical gradient of piping strongly depends on the rock stress conditions and material properties.

If the minimal principal rock stress component /σ_{min}/ exceeds the water pressure /p/

$$\sigma_{min} > p \qquad /4/$$

the fissures cannot open in soft rocks. Therefore, even fissured, destroyed /undermined/ soft rocks can be protective layers if inequality /4/ holds [13, 14, 15].

The effect of the water pressure difference /$\Delta p = p-\sigma_{min}$/ enlarging the fissures /Δy/ is shown in Fig. 4. for different rocks according to a simplified analytical model. The figure points out that in case of hard rocks /case a.// the change of fissure sizes can be eliminated but in case of soft rocks /case c.// fissures opened by water pressure may exceed one centimetre or more. This enlarged size of fissures is enough for an intensive water inflow, where the dynamic effects cannot be neglected.

1.2.2.The final stage of piping

After the start of piping the most important effects are as follows:

- the deflocculation which is important only in case of free Na^+ ion content of the protective layers /Sherard 1977/
- the impulse transport from the fluid phase /water/ to the solid phase /rocks/.

According to mining experience the mechanical effect /the impulse transport/ may be the basic effect in many cases. The erosion effect of the solid particles on the water /e.g. sandy water inrushes/ may absolutely eliminate the protective effect of soft rocks [14].

The impulse of water flowing in a rock fissure can be expressed as a function of the actual hydraulic gradient.

If other parameters of the impulse transport are regarded as constant, the final stage of the piping process can be also expressed as function of the actual hydraulic gradient. The stability of the rock mass of pillars can also be expressed as function of the actual hydraulic gradient, even for impermeable rocks [23].

The role of a critical value of the hydraulic gradients detected in many different phenomena of rock-water interaction points out the common features of these phenomena. According to the approaches of Kapolyi and Asszonyi [23] the conditions of rock movements, even the failure process are stronly determined by the conditions of energy transport. The hydraulic gradient represents the gradient of the potential energy source in the unit mass of water. The energy transport, determined by the gradient of the specific energy source, is one of the components of the gradient, may determine the rock failure process in many cases of the rock-water interaction.

Because of the heterogeneities and parameter uncertainties the critical hydraulic gradient may be expressed as a random variable.

Fig. 5/a presents empirical curves of the yield of karstic water inrushes as a function of the inverse of the actual gradient in the protective layer according to the observation data of about 1000 mine water inrushes. [16]. Fig. 5/b presents the empirical distributions of the yield of the same inrushes for different intervals of actual hydraulic gradients. Under the conditions investigated

$$q_{max} < 2,5 \ m^3/min$$

if $I_a < 5$ m/m for all cases of experience.

As a consequence of the above discussion, the risk of the start of piping and even the final stage /result/ of piping can be expressed in the form of critical values of the hydraulic gradient. These critical values have to be expressed in form of empirical density functions for different geological and mining conditions. The empirical distributions of the critical values of hydraulic gradients can be used for predicting the risk of mine water inrush or the maximal yield of inrushes for analogeous conditions. These values can also be used for sizing water barrier pillars.

1.3. The effects of mining operations on the properties of protective layers

Excavation then abandoning of underground openings change the properties and conditions of surrounding rock area. As a consequence, zones of changed rock properties, called "loosened zones" must not be taken into account as protective layers.

Around tunnels and roadways the size of the "loosened zones" is only some metres. Short borehole tests and experimental data may be used to determine its sizes. Because of the small sizes of the loosened zone around tunnels /roadways/ their uncertainties are of not too much importance. /If the loosened zone around a given tunnel may vary between 2-7 m, the maximum is 7 m, that is, in any case 10 m may be taken into consideration without any difficulty/.

The loosened zone in an undermined area of longwall faces may exceed 200-300 metres depending on many factors. Under other conditions /in soft rocks/ it may not be more than 15-40 metres. Therefore the determination of the realistic size of the loosened zone of a longwall facing operation has a great importance for sizing water barrier pillars.

Fig. 6/a and 7/a illustrate the undermined areas in cases of hard and soft rocks. Fig. 6/b and 7/b present the water conductivity detected by boreholes in the undermined area.

A comparison of the two extreme cases: the soft and the hard rocks lead to important points:

- The form of the curves is the same. A destroyed and a fissured zone can be detected in both cases but some important differences between hard and soft rocks have to be pointed out. These are:

-- the size of the fissured area is larger in hard rocks;
-- the effect of rock stress on the conductivity may be eliminated in hard rocks, but it is important in soft rocks. The rock stress may close the fissures of soft rocks.

As a consequence of the above mentioned difference between soft and hard rocks:

- the effects of the consolidation of the undermined area can be eliminated in case of hard rock, but it cannot be achieved in case of soft rocks;

- the conductivity of the undermined area of hard rocks can be determined by borehole test /pumping tests, drill steam tests, etc./ but the same methods cannot be used in case of hard rocks, where piping process may occur;

- a part of the fissured zone of the undermined area may also be taken into account as a protective layer under certain conditions;

- in case of soft rocks, those parts of fissured zone have protective effect, where the water pressure does not exceed the minimal principal rock stress and the actual hydraulic gradient is less than the critical one;

- in case of hard rocks the water conductivity may be regarded as a permanent value, and the total fissured zone can be taken into account as a hydraulic resistance element to limit the infiltration rate /Fig. 7./.

Between the above mentioned two extreme cases: "hard" and "soft" rocks, a number of intermediate cases occurs in the mining practice. Special field tests and mining experience under analogeous conditions have to use for determining the loosened zone for given conditions of rocks and mining activities [7, 9, 15, 22].

A simplified model for determining the vertical size of the loosened zone under condition of longwall facing may be, as follows:

$$H_1 = A \cdot M /1-\eta/ + X + \Delta X - h \qquad /5/$$

where M is the thickness of the exploited slice
A is a constant,
η is the factor of the efficiency of the backfilling
X is that part of the fissured zone which has no protective effect; X depends on the thickness of the slices, the rock properties, etc.
ΔX is the increase of X due to exploiting more slices
h is the time dependent compression of the loosened zone.

For more slices $/M = n \cdot V/$, the loosened zone of the exploitation of the first slice can be determined by function /5/ where M specified as $M = V$ and $\Delta X = 0$. For the next slices the same form of equation can be used, but the value of A' may be changed and ΔH has to be specified in function of M /Fig. 8/b/.

For soft rocks the change of fractured zone can be eliminated [14, 24/b, 26], consequently $A' = 0$. In this special case the enlarging of loosened zone $/\Delta H/$ is equal with the enlarging the X-zone$/\Delta H = \Delta X./$ Fig. 7/b presents the results of a finite element analysis as compared to empirical data [12, 13, 14]. The boards of the slices have to be formed "a slope" for minimizing the rock deformation /as shown in Fig. 7/b/.

The total thickness of loosened zone for more slices is $H = H_1 + \Delta H$.

Some remarks on the empirical bases of the components of the above functions have to be mentioned:

A number of empirical data [1, 9, 13, 14, 22, 24/b, etc.] demonstrates that the thickness of the fractured zone is a quasi-linear function of the thickness of the first slice, and the change of the fractured zone during exploitation of other slices may be neglected in most of cases.

The constant A is varying between 2 and 5. For soft rocks A is varying between 2 and 3 [14, 22, 26], and for hard rocks 4 and 5 [7, 9, 22].

X-zone is more sophisticated one:

In cases of soft rocks the X-zone is "the zone of decreased rocks stress" where $\sigma_{min} < p$ [14].

In case of hard rocks the X zone is a part of the fissured zone, where local fractures occur. For this reason, it has no protective effects.

According to the field tests and finite difference analysis /fitted to the empirical data/ the X-zone is not a linear function of M /Fig. 8/c/ [15] and the thickness of the X-zone strongly depends on the number of slices /on the total thickness of the exploitation/.

Term h represents the effect of consolidation of the undermined area. This effect is important in soft rocks. Under conditions of coalfields Tatabánya and Dorog h = 0,3 M has been observed during 30 years /according to Harsányi/[2].

The above model is compared with many empirical data [7, 9, 15, 22, 26]. Because of the acceptable agreement these curves may be used as a first approach for determining of thickness of the loosened zone .

The form of the loosened zone can be taken into account as a trapezoid for longwall facing /Fig. 6/a, 7/a/.

2. Sizing

First basic guidelines will be presented then simplified tipical case examples will also be provided.

2.1. Basic guidelines for sizing

First the necessity and possibility of using pillars have to be decided, then sizing may follow.

2.1.1. Preliminary considerations

First, rock conditions have to be investigated because pillars can be used only in cases of the rock between the aquifer and mining openings are considered as protective layers.

The necessity of using pillars has to be determined next, analysing the possible interactions of the aquifer and mining activity.

Water barrier pillars are necessary in the following cases:

/i/ The yield of water inflow can be extremely large, e.g. lakes, rivers, flooded abandoned mines, large karstic caves on the roof strata.

/ii/ The mine water inflow can induce dangereous rock movements /e.g. slim inrushes/

/iii/ The dangerous gas content of the water inflow can exceed the permitted limit.

In the above listed cases, the only reliable way of control is the limitation or elimination of the risk of mine water inflow, using water barrier pillars.

In some other cases, the use of water barrier pillars may be one of more possible alternatives or elements of mine water control system.

Let us mention some typical cases of the above mentioned conditions:

Case 1. Protection against inrushes stemming from flooded mine workings or, sandy reservoirs may be solved by the following three possibilities of control:

- drainage of the flooded mine workings /or sandy reservoirs/ from the surface;
- application of water barrier pillars;
- preventive drainage from underground openings using boreholes for drainage and provisional water barrier pillars for protecting the drainage operation.

Case 2. Protection of mining operations against water inflow stemming from neighbouring mines. Each of the neighbouring mines may be flooded due to water inrush or due to abandoning. The following alternatives can be used:

- water barrier pillars between the neighbouring mines
- pumping station of sufficient capacity for the two /or more/ neighbouring mines.

In some of the above mentioned cases, preliminary determination of the pillars' sizes may be also necessary for decision making because the quantity of mineral resources of the pillar may also be an important factor for economic decision.

2.2 Methods, approaches for sizing

The main steps of sizing are as follows:

- determination of the loosened zones around the mining openings /see subsection 1.3./;

- sizing the pillar with regard to the necessary hydraulic resistance of pillars /subsection 1.2./;

- checking the mechanical stability of the rock mass of pillars /see subsection 2.1./. If this analysis shows unstable state of mechanical equilibrium, the pillar must be enlarged and the mechanical state has to be checked repeatedly.

The requirements for sizing are depending on rock properties.

In cases of "protective layers of constant permeability" and of "limited water conductivity", the sizes of pillars have to be determined regarding the permitted yield of water inflow. The limit-value of the water inflow may concern the total yield of mine water inflow, or the maximum yield of a single water inrush or both.

In case of the limitation of the total mine water inflow the limit of the yield of water seepage /Q_s/ is determined by the output capacity /Q_p/ of the pumping station.

$$Q_s < Q_p \qquad /6/$$

Becasue of the required safety level of the mining operations against flooding, the parameter uncertainties /model uncertainties/ and the reliability of the pumping system have to be taken into account as well[30]. Consequently, the yield of the water seepage can be assumed as a random parameter /as a density function Q_s/p/ and the output capacity of the pumping station should also be given as a random parameter /as a function of the reliability of pumping system performance/. The available output capacity /Q_p/$_a$ /p/ is also a random function.

The necessary requirement of an existing water barrier pillar for every time period is as follows:

$$/Q_s/\ /p/ < /Q_p/_a\ /p/ \qquad /7/$$

Methods for determining random functions of Q_s and /Q_p/$_a$ are available and used in the mining practice [4]. For all other cases of the protective layers, the risk of piping is determined by the following inequality:

$$I^{/p/}_{actual} < I^{/p/}_{critical} \qquad /8/$$

in a given confidence. $I^{/p/}_{critical}$ is discussed in subsection 1.2.

<u>Methods of sizing</u> also depend on properties /types/ of protective layers.

Two main ways of sizing can be distingueshed:

1. In cases of protective layers of constant permeability the sizing of the pillar may be effected as an underground water seepage problem, using wellknown analytical methods or numerical techniques /finite element, finite difference/.

The location and the parameters of the aquifer and the protective layers are given. Mining openings and failure zones can be taken into account as drainage elements. Different sizes of pillars have to be analysed by the above mentioned way for determining the proper size in accordance with inequality /8/.

2. In all other cases, the actual hydraulic gradient has to be determined for all possible ways of water seepage between the aquifer and mining openings. Loosened zones have to be taken into account as mining openings. The small values of the actual gradient show the most dangerous way of seepage. $/I_{actual}/_{md}$. The actual gradients of the most dangerous way of seepage have to be determined for different sizes of pillars. The proper sizes of the pillars are obtained if

$$/I_{actual}/_{md} = I_{critical} \qquad /9/$$

in a required level of confidence.

Some simplified case examples will now demonstrate the above guidelines for sizing pillars.

3. Brief case examples

3.1. Water barrier pillars between two mines

Fig. 9. presents a section of two coal-mines A and B. Longwall facing operations are planned for both mines. The water barrier pillar between the two mines will be sized. The rocks of the pillars are coal, clay and marl. The coal and the marl regarded as a protective layer of limited water conductivity. The clay is waterproof in its original conditions, but after the seepage starts, the pores may be enlarged "unlimitedly".

For both groups of rocks the permitted values of hydraulic gradients are given by empirical data /see Fig. 4. and Fig. 5/a./.

For the given conditions:

- marl is able to limit the yield of water inrush if I 5,5 m/m
- the effect of the coal is the same if $I < 3,5$ m/m
- the clay is able to protect against the start of the seepage if $I < 5,0$.

The size of the pillars has to be determined according to the following basic considerations:

1/ The actual hydraulic gradient for all possible ways of filtration must not exceed the above listed "permitted values".

2/ The rock mass of pillar sized according to the first consideration /mentioned above/ has to be in stable state of equilibrium. /If not, the sizes have to be enlarged and the equilibrium repeatedly checked/.

The usually used steps of problem solutions are as follows: The loosened zones which must not be considered as protective layers are determined according to equation /5/ using empirical curves of rock type No. 3. according to Fig. 8. The total explioted thickness of coal seams is 6 m, the planned effective thickness of slices 2,5 m. Total backfilling is planned to use /$\eta = 0,7$/. Due to the possibility of the changing of time scheduling of the exploitation in both mines, the most dangereous condition: simultaneous facing has to be taken into account. This consideration means that the consolidation of the loosened zones must not be taken into account.

According to the above considerations, sizes of the loosened zones are given in Fig. 8. The loosened zones are regarded as mining openings. The path of filtration between the two mines have to be checked by calculating the actual values of filtration for a given size of pillar.

The possible ways of filtrations may follow the tectonic lines, the surfaces of seams, mainly in the coal seam, where the permitted value of the hydraulic gradient is minimum.

The shortest geometric pathway between mining openings has to be also checked. /The paths of filtration are marked with numbers/. Under conditions of rocks of different permitted hydraulic gradients, the use of the coefficient of equivalence may simplify the numerical operations.

The coefficient of equivalence shows how much the thickness of the rock X is equivalent with rock Y regarding the permitted values of the hydraulic gradient. In our case the clay will be the unit and the coefficient of equivalence is 3,5/5 = 0,65 for coal, and 5,5/5 = 1,1 for marl. The equivalent lenghts of all pathways of filtration are tabulated in Fig. 9. Because of the uncertainties in the geological data /stratification, location of tectonic faults, etc./ each path of filtration is of 5 m. Considerations have to be taken on specification of the water pressure.

Abandoning one of the mines, it may result in flooding. The water level in the mine depends on the piezometric head of the reservoirs. In many cases, the maximum piezometric head of ground water determines the maximum level of flooding /see mine B/. In some other cases, the minimal geodetic level of the shaft collar may limit the maximum level of flooding /see mine A/.

Having determined the critical values of water pressure, the actual hydraulic gradients for all possible paths of filtration are also listed in Fig. 9.

The path pertaining to the maximum value is the critical one. The actual gradient exceeds 5 m/m, consequently the size of pillar has to be enlarged by a chosen value and the actual gradient for the critical path has to be repeatedly checked. According to the tabulated figures, the second step of sizing gives a satisfactory result. The same path of sizing is usually used for other areas along the boundary of two mines.

For the above case the stability of the rock mass of the sized pillar was checked by a simple empirical approach. In mines A and B and in other mines of the same coalfield, mining experience has been collected on the conditions of pillars protecting the main roadway from the rock stress effect of langwall facing operations. This experience shows that pillars of 60-80 metres between two longwall facing operations have enough stability.

3.2. Water barrier pillar as an element of a combined control system

Fig. 10/a presents roadway driving and longwall facing operations in mine C, approaching a lake on the surface. The risk of a water inrush from the lake has to be absolutely eliminated. A limited seepage from ground water reservoir may be allowed. The lake is surrounded by a sandy ground water reservoir. The protective layer is soft clay.

The highest possible maximum size of the fissured zone surrounding the roadway is specified as 10 m. The coefficient of the equivalence of the sand may be regarded as zero comparing with clay.

According to this first approach, the ground water reservoir is regarded as a lake. This approach can be used for determining the size of the water barrier pillar for the roadway driving operations.

The same considerations and methods can be used which were presented for mine A and B. But this approach cannot be used for the facing operation because the loosened zone of the facing operation gives a direct contact with the ground water reservoir. Therefore more sophisticated approaches have to be used for determining the protective effect of the sand / a loose granular one/.

The most simplified but safest model may be the analogy of an open pit mine under the same geometric and geological conditions /see Fig. 10/b/. A number of experience is available on the stability of slope under conditions of water seepage.

Though rock stress conditions, consequently rock stability conditions are not the same in open pit and in underground conditions, the same basic considerations may help us.

Figure 11. presents calculated curves of rock stress conditions on the surface of the slope and of the same point under underground conditions. Under underground conditions a rock mass loads the surface of the "equivalent open pit", consequently the equilibrium is less critical /comparing with the open pit/.

The safe distance of an equivalent open pit from the lake can be regarded as a safer size of water barrier pillar. According to the experience on open pit mines, the distance may exceed 100-200 metres or more, consequently the water barrier pillar occupies a great mass of coal resources.

The analogy of open pits points out a reasonable solution of minimizing the size of the pillar. This is the water level lowering in the ground water reservoir /using gravitationally operated boreholes from the roadways/.

This example points out that the use of pillars may be one of the elements in a control system and the size of the pillar really depends on the mode of mining activity.

3.3 Water barrier pillars in hard fissured rocks

Figure 12 presents a fissured ore body /andesite/ surrounded by strongly carstified limestone reservoir. The ore bodies are planned to exploitate by a system of chambers and pillars. The requirements are as follows:

- the maximum yield of a water inflow into a roadway must not exceed 0,5 m^3/min, and into chambers 1,6 m^3/min because of the highly dangereous gas content of water,

- the maximum of the total mine water inflow is also limited /because of environmental protection requirements/.

Only the key considerations will be mentioned.

The inflow into the roadways and chambers approaching the boundary of the ore body are mostly determined by local parameters; consequently the uncertainties on the geometry of the boundary of the ore body and the local values of the water conductivity are taken into account as random values. Methods for detecting and modelling of the uncertainties are available [3].

The total inflow into the mine can be taken into account using average values of reservoir parameters and simplified geometrical models, but regional hydrogeological conditions have to be carefully investigated.

The local inrushes and the total inflow should be determined for different sizes of water barrier pillars. The proper size of pillar will be the minimum one, when the above listed requirements are all met.

CONCLUSIONS

Water barrier pillars are very important tools for mine water control. In some special cases the use of water barrier pillars is the only way for an effective mine water control. In many other cases the pillars are important elements or a possible alternative for an effective and economic control system.

Water barrier pillars can be used only in those cases when the rock mass locating between the mining opening and the aquifer has mechanical stability against water pressure and the necessary value of hydraulic resistance against water inflow. Both requirements have to be investigated under given geological conditions and for given mining operations. Consequently, the use and sizing of water barrier pillars require several considerations on rock-water interactions and the planned mining activities as well. In many cases of mining experience, in-situ measurements and sophisticated methods of modelling should be simultaneously used for sizing.

Mine Safety Prescriptions in Hungary are based on the approaches and methods presented in this paper.

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List of Figures

Fig. 11. Comparison of the rock stress conditions in the boundary of the undermined area and in the surface of slope of the equivalent open pit

Fig. 12. Sizing water barrier pillars in fissured rocks /a case for example/

Fig. 1

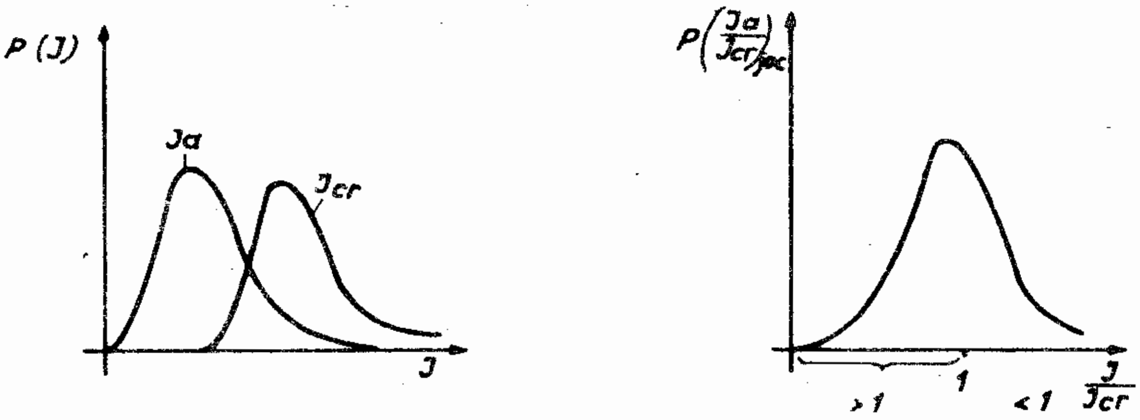


Fig. 2

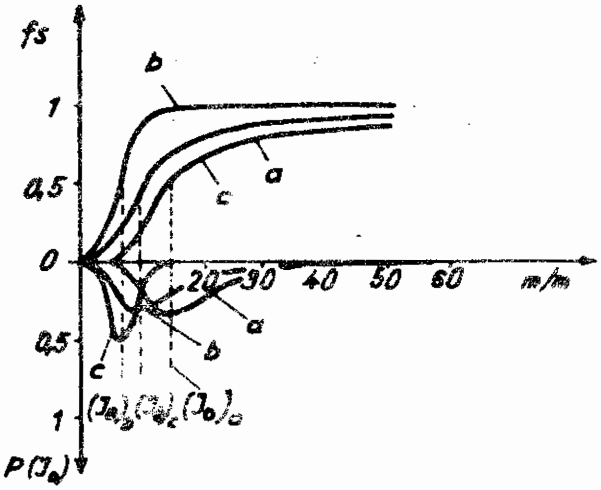


Fig. 3

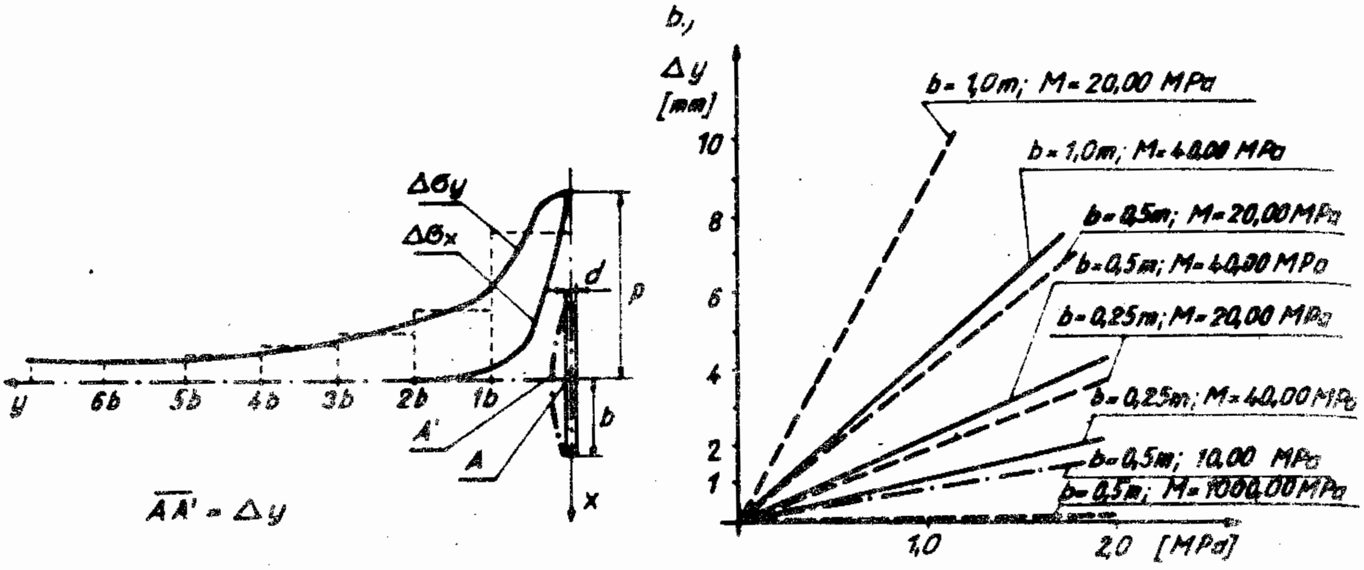

b.)
Δσy
Δσx
d
p
y
6b
5b
4b
3b
2b
1b
A'
A
b
x
$\overline{AA'} = \Delta y$
Δy [mm]
10
8
6
4
2
1
1,0
2,0 [MPa]
b= 1,0m; M= 20,00 MPa
b= 1,0m; M= 40,00 MPa
b= 0,5m; M= 20,00 MPa
b= 0,5m; M= 40,00 MPa
b= 0,25m; M= 20,00 MPa
b= 0,25m; M= 40,00 MPa
b= 0,5m; 10,00 MPa
b= 0,5m; M= 1000,00 MPa

Fig. 4

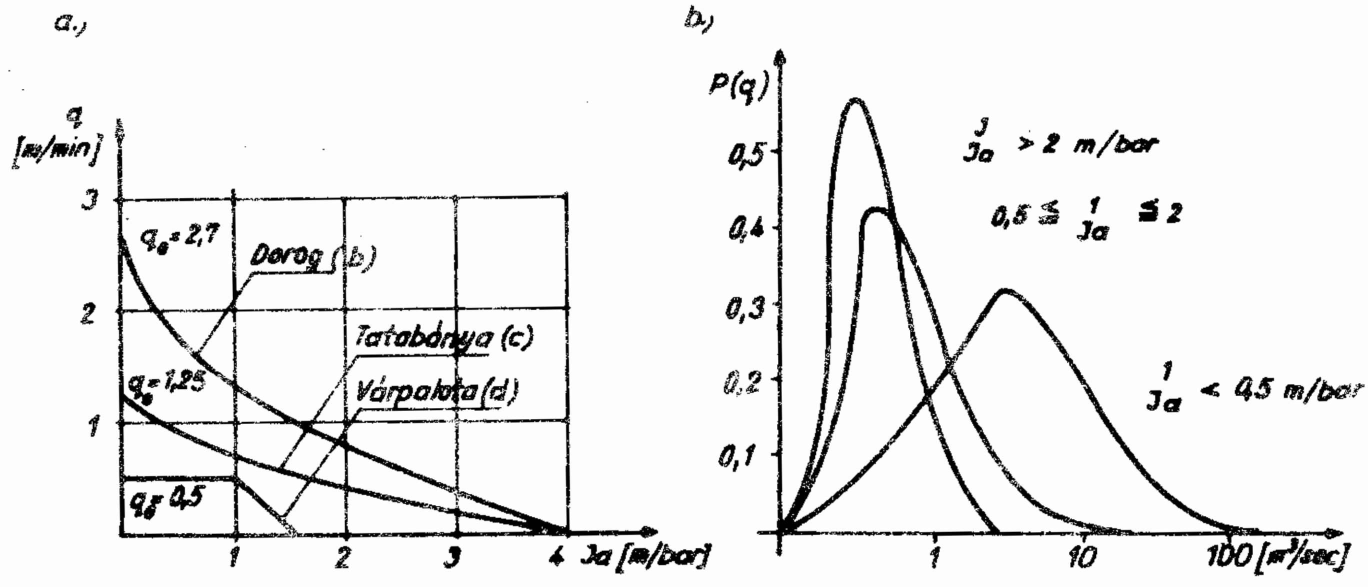

a.)
b.)
q [m/min]
3
2
1
$q_e = 2{,}7$
Dorog (b)
Tatabánya (c)
Várpalota (d)
$q_e = 1{,}25$
$q_e = 0{,}5$
1
2
3
4
Ja [m/bar]
P(q)
0,5
0,4
0,3
0,2
0,1
$\frac{J}{Ja} > 2$ m/bar
$0{,}5 \leq \frac{1}{Ja} \leq 2$
$\frac{1}{Ja} < 0{,}5$ m/bar
1
10
100 [m³/sec]

Fig. 5

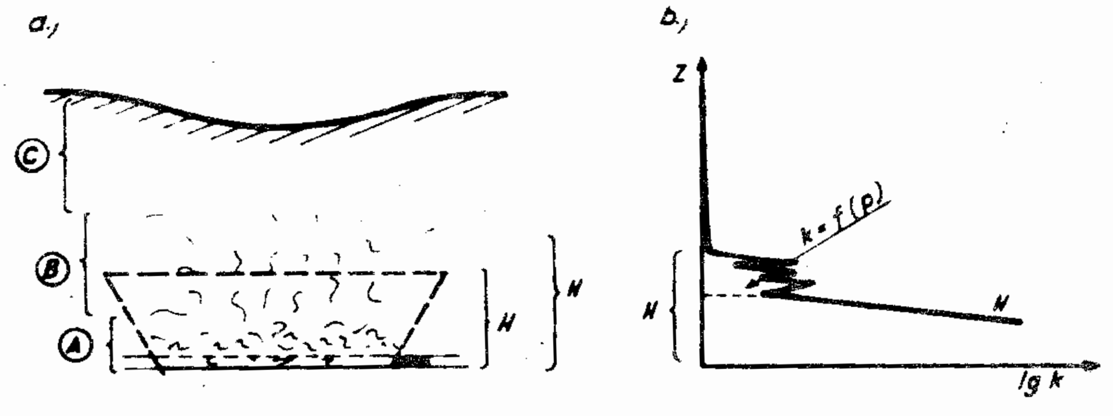


Fig. 6

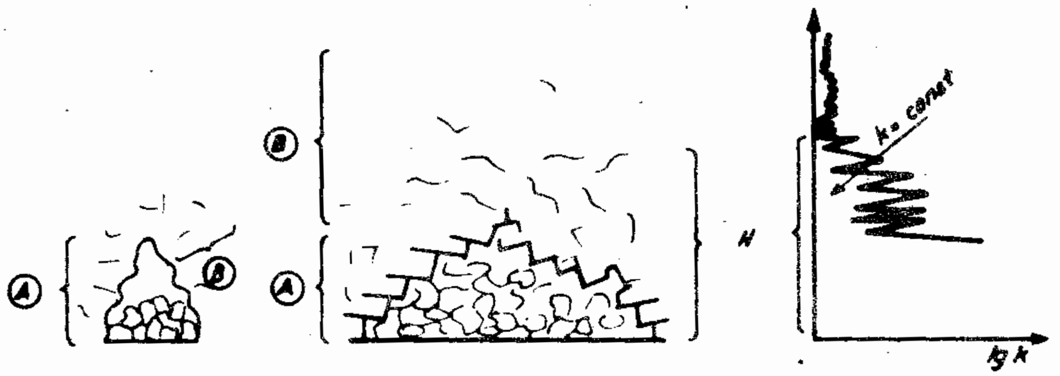


Fig. 7

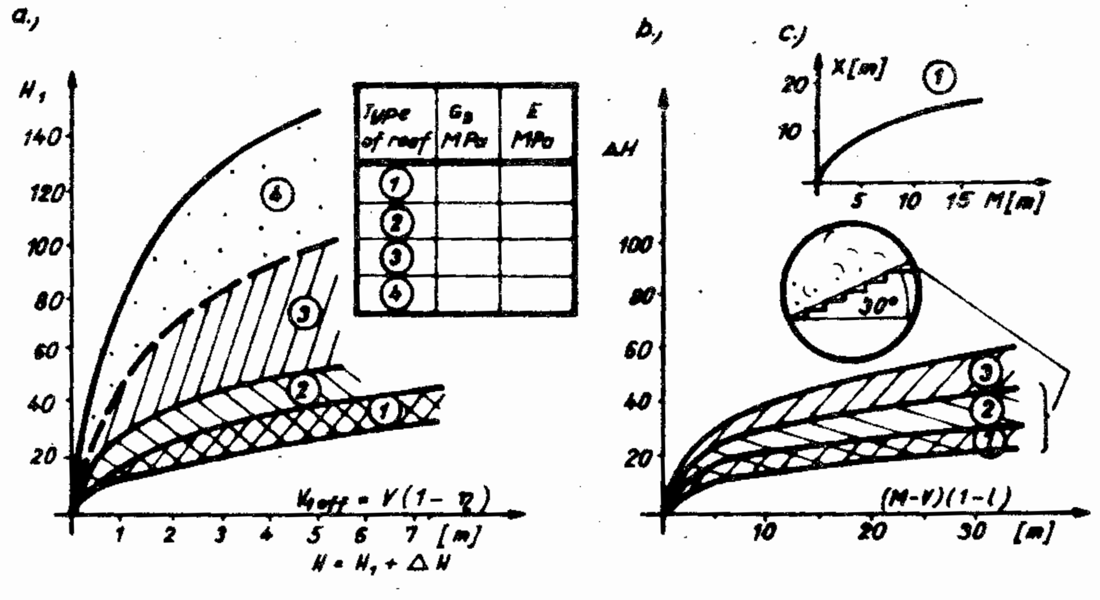
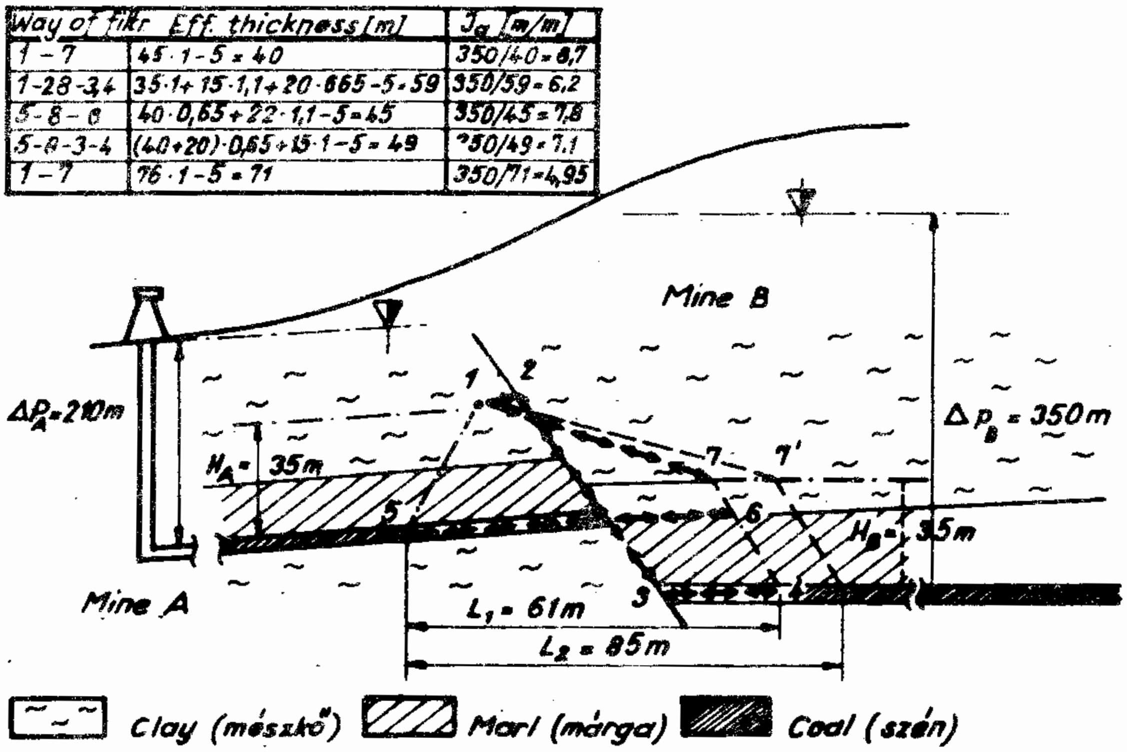


Fig. 8



Way of filtr	Eff. thickness [m]	J_q [m/m]
1 – 7	45·1–5 = 40	350/40 = 8,7
1-28-3,4	35·1+15·1,1+20·665–5 = 59	350/59 = 6,2
5-8-6	40·0,65+22·1,1–5 = 45	350/45 = 7,8
5-8-3-4	(40+20)·0,65+15·1–5 = 49	350/49 = 7,1
1 – 7	76·1–5 = 71	350/71 = 4,95

Fig. 9

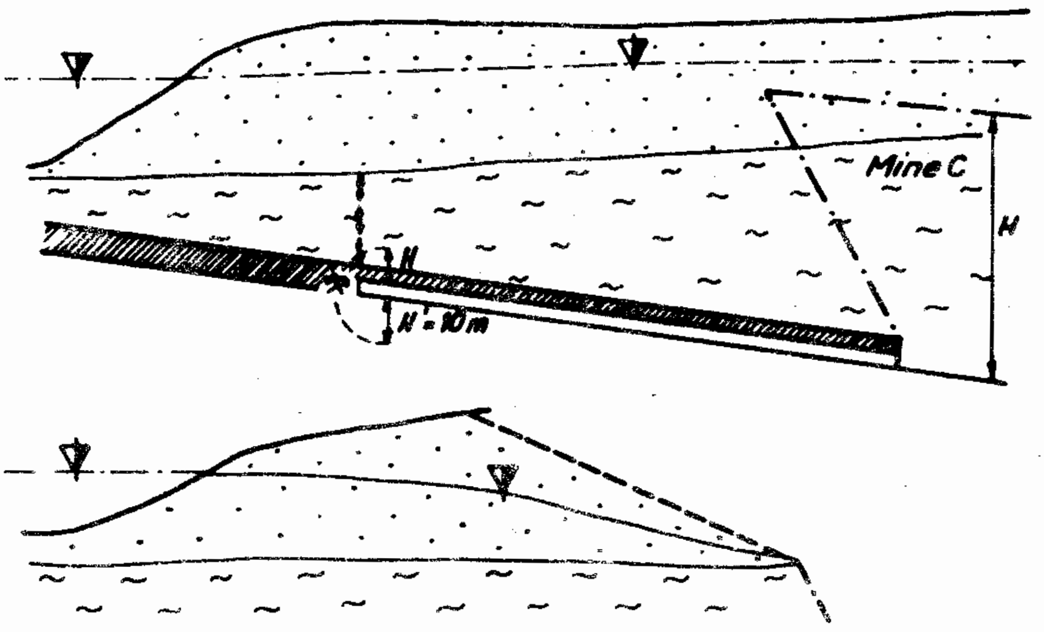
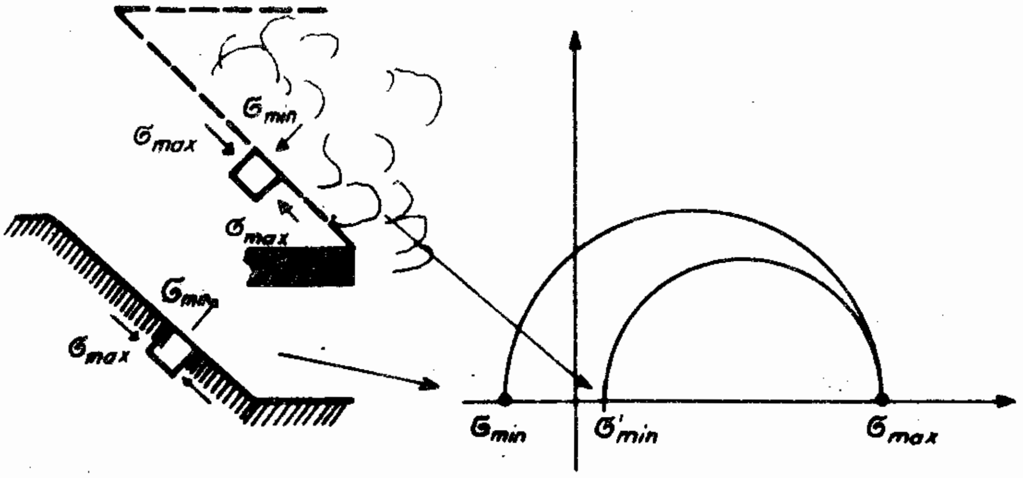
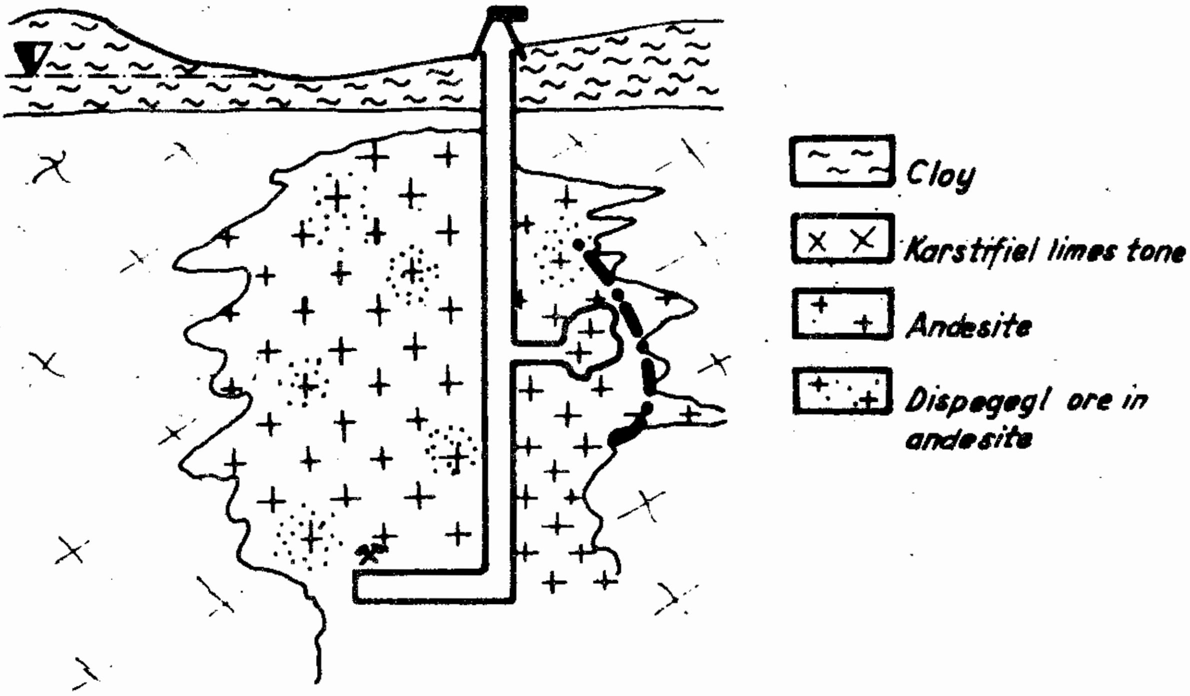


Fig. 10



σmin
σmax
σmax
σmin
σmax
σmin
σ'min
σmax

Fig. 11



Cloy
Karstifiel limes tone
Andesite
Dispegegl ore in andesite

Fig. 12