INTERMEDIATE-LAYER DEWATERING AND GRAPHICAL PROGRAMMING OF ITS OPERATION

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SUMMARY

A special dewatering method is described which was developed at the Mátraalja Coalmining Company in 1965 by the author and his partner. The method is based on the triggering and maintenance of artificial drainage. The method has been in operation at three open-pits of the Thorez mine since 1969, after a 3 year experimental period. Application has resulted in a 50 % reduction of dewatering cost. Applied hydrogeological conditions are explained. Some characteristic configurations of the well network depending on hydrogeologic conditions, are presented. Techno-economic merits are emphasized. A simple linear graphical method is shown for the continueous operation and supervision of the system. Evaluation method of the program files of observation wells and the applicability of this evaluation for operation scheduling and production planning are outlined. The method has proved to be efficient and can be transferred to other open-pit mines.

INTRODUCTION

Open-pit mining at the Thorez mine offects 3-8 confined aquifers consisting mostly of fine sand. Piezometric levels were as high as /or sometimes higher than/ the proximity of the ground surface prior to mine opening. A drawdown of 40-90 m is necessary for mining. There is considerable inhomogeneity both vertically and horizontally in the aquifers.

Dewatering started by the help of roadways in the middle of 1960, but the resulting high costs led to the application of deep wells in 1963. However, the high requirements of manpower and equipment of this latter method called for more advanced solution. In this line, the study of foreign examples and home research resulted in a decisive change, the development of the intermediate-layer dewatering method.

THE INTERMEDIATE-LAYER DEWATERING AND ITS APPLICABILITY

Intermediate-layer dewatering can be applied if several aquifers are to be drained or their piezometric levels are to be reduced. If such an aquifer/s/ can be found below the deepest mining level of an open-pit or an underground mine - in an economically accessible depth - from which more water can be drained than from all upper aquifers, this aquifer is an appropriate intermediate /sink/ layer. Piezometric level in this layer is decreased until it is lower than those in the other aquifers. Next, layers are connected by wells and water from the upper aquifers is conveyed through these intermediate wells into the intermediate layer. Water is transported in the intermediate layer to pumping wells. Principles of the method are, thus, the development of an intermediate layer and the communication among the layers. It may be called as a dewatering method by artificial communication.

It is sufficient to bring about head difference for initiating the process. In a favourable case, this may be given already before mine opening. In order to maintain the process one has to maintain this head difference. In this respect, recharge to layers must be caught outside the mining boundary. After that, within the mining boundary, one has to drain only the static water resources.

Principles of intermediate-layer dewatering are illustrated in Fig. 1, and alternative well networks can be seen in Fig. 2. Spacing and configuration of pumped and intermediate wells are determined by the prescribed ratio of discharges from the various layers.

The simplest case corresponds to the following inequality:

$$q_{vny} > \sum_{1}^{n} q_{v1} + \dots + q_{vn} \qquad /1/$$

where q_{vny} is the discharge from the intermediate layer and $q_{v1}, \dots q_{vn}$ are discharges from the aquifers to be drained.

If inequality /1/ holds even before mine opening, dewatering can be effected according to Fig. 1B. The corresponding well network /Fig.2A/ consists of intermediate wells /12/ conveying natural recharge to pumped wells, while static water resources are sunk by drilled intermediate wells /11/ into the intermediate layer and through that water arrives in the pumped wells.

If

$$q_{vny} \cong \sum_{1}^{n} q_{v1} + \dots + q_{vn} \qquad /2/$$

holds, then the natural recharge of the aquifer cannot load the intermediate layer. In that case, dewatering is effected according to Fig. 1A. Natural recharge of layers 1 ... 4 is drained by the pumped wells /10/. Discharge ratios within the closed area can be analyzed by known well formulas. Discharge of a single well in a confined aquifer can be calculated as

$$q_v = 2.73 \frac{kMs}{\lg\frac{R}{r}} \qquad /3/$$

shere
k: the seepage coefficient
M: aquifer depth
s: drawdown
R: radius of the cone of depression
r: well radius.

Discharge of an inner intermediate well decreases quickly since R_k is small:

$$R_k = 0{,}5\ L \qquad /4/$$

Drawdown in time t_i is interpreted also in a different way within the closed boundary:

$$\Delta S_i = H_m - h_o \qquad /5/$$

Notations can be seen in Fig. 1.

Thus, discharge of an intermediate well is, under still confined conditions in time t_i

$$q_{vi} = \frac{2{,}73}{\lg\frac{R_k}{r}} /k_1 M_1 \Delta S_{i1} + \dots + k_n M_n \Delta S_{ni}/ \qquad /6/$$

On the other hand, pumped discharge from the intermediate layer will increase, since piezometric head H_m increases by ΔH_m, as a result of the discharge through intermediate wells /Fig. 1/.

Probably, only 50-60 % of the filtered part /facing the open-pit/ of the pumped well receives water from the intermediate layers. This limitation is, however, balanced by the decrease of R, leading to higher discharges. It is not clear yet which R_m: 1-2-3 /Fig. 1/ is the real one but this information is not inevitably necessary for practice. As shown, the initial high discharge from the aquifers sharply decreases.

Initial higher discharges are, then "pushed" into the intermediate layer, as an effect of the relatively great head difference ΔH_m. In order to decrease the harmful effects of the initial high discharges, intermediate wells are drilled in series, one protected by the drawdown of the previous one.

Thus, the applicability of the method is not constrained by inequality /1/. If natural recharge is caught by a line of properly operating wells, intermediate-layer dewatering can be effective even if inequality /1/ is the opposite. A well system as shown in Fig. 2B can also be helpful under extremely adverse hydrogeologic conditions. Greater initial discharges of the static resources are pumped by wells /13/, the operation of which are stopped when discharges decrease.

TYPE OF WELLS FOR INTERMEDIATE-LAYER DEWATERING

Triggering well: Its function is to establish and maintain the intermediate layer effect. It is filtered only within the intermediate layer. Its radius fits the dimension of a submergible pump. It needs electric energy and water conveyance.

Pumped terminal well: It drains the intermediate layer and all the other aquifers. It has filtered parts along every aquifer, fits the dimension of a submergible pump and requires electric energy and water conveyance.

Intermediate well drains aquifers within mining boundary and conveys drained water into the intermediate layer. No pumping is necessary; it has a smaller radius with PVC casing to prevent rupture of mining machinery. It becomes shorter and shorter according to mining strips. After reaching the first strip, the well is filled with gravel or closed with a permeable packer and continues to operate under the mining level.

Intermediate terminal well has the same construction as the previous well. Its function is to direct natural recharge arriving in the mine into the intermediate layer.

Observation wells are drilled among well lines. Piezometric heads are to be measured separately, thus layers are separated in an impermeable way.

OPTIONS OF REALISATION

A number of realisations is possible, depending on the form, magnitude, production, schedule and hydrogeologic conditions of the mine. Dewatering of single or adjacent mines is also different. More important options are as follows:

Simultaneous dewatering of a bounded area [2] may be used during mine opening when e.g. the area of the opening pit is encircled by triggering wells or terminal wells. Intermediate well system is also sunk. Pumping starts when all the wells are completed. The drainage of aquifers and triggering of the intermediate layer is simultaneous. Its advantage is to minimize pumped water from recharge, however this option is not flexible.

Advancing line of laterally closed wells

Lateral slopes are protected by terminal wells. Lateral wells are longer, corresponding to a lead time of dewatering period /3 years in the Thorez mine/. Intermediate wells are completed in several lines in front of the mining face. No terminal wells are prepared parallelly with the face in the direction of mining. Terminal wells are substituted by intermediate wells /Fig. 2.C/. Outcropping part of the mine can be protected from backward by the inner dump if it is sufficiently impermeable. According to the advancement of mining, terminal wells become shorter and shorter.

Subsequent operation[2] is justified if some layers of less conductivity near the surface can be drained only by a dense network of wells. If, however, the next layer is a leaky aquifer, it can receive water from the upper layers. Adjacent wells convey water from the leaky aquifer into the main intermediate layer /Fig. 3./. Such option is used in the Keleti-II open-pit mine of the Thorez mines, leading to a 30 % reduction of drilling activity.

TECHNO-ECONOMIC ADVANTAGES

Drainage efficiency is high since the remaining parts of intermediate wells cut by stripping are still operating. Dewatering period becomes longer just in the most efficient time of removing water left in the aquifers.

The decrease of pumped wells simplifies the operation /e.g. in the Thorez mine every sixth or seventh pumps are pumped/. Application of highly efficient pumps is possible in the fewer wells of higher discharge. The smaller number of pumped wells results in savings in the energy supply network and equipment.

Additional sinking of wells is easy since the intermediate layer exists under the whole mining area. No energy supply and water conveyance are necessary. Intermediate wells can be drilled even subsequently from mining levels.

The number of checking points is higher. By using water level observations in intermediate wells the dewatering process can be controlled and less observation wells are necessary. Intermediate wells are cheap since requirements due to submergible pump operation are eliminated. The intermediate layer can be maintained even under the inner dump of it is also to be dewatered.

Economic advantages of the method are illustrated by the following numbers:

100 % is the cost of dewatering by roadways
82 % is the cost of dewatering by deep wells
40 % is the cost of dewatering by intermediate wells.

GRAPHICAL PROGRAMMING OF DEWATERING

Dewatering plans of the Thorez mine have been prepared by analytic tools in the KBFI [6]. Main outputs of the plans are: necessary discharge for the planned drawdown, spacing, dewatering time. Plans generally cover 5 year periods. Plans referring to well-explored areas properly fits reality. The greatest problem of this method is that hydrogological exploration is not detailed enough. Detailed exploration takes time and is expensive, thus engineers are often bound to use estimated values. As a result, over some part of the inhomogeneous mining area there is a difference between planned and observed dewatering states. Dewatering faster than planned is ineconomic, slower one hinders production. Economic and reliable dewatering operation would need the knowledge of the drawdown function in advance for every aquifer in each observation well. In this case, overdesign and underdesign could be checked. However, these functions could not be determined due to the above reasons [4].

Technological and economic importance of the problem required a better solution . The study of long-ago observed water level functions of observation wells in the Thorez mine led to the following conclusion in 1973: Drawdown function can be fitted well by a straight-line over a hydraulically closed area, using advancing dewatering and normal operation schedule [5].

Linearity does not hold in the initial dewatering period and in case of considerable changes of discharge. This conclusion has made possible to apply a very simple scheduling and supervision method.

Scheme of graphical programming is illustrated in Fig. 4. Water level diagrams /y, t/ of observation wells are used, containing also the mining schedule. A strip of level difference Z_0-Z_1 reaches the observation well in time t_1, as given in the mining schedule. The period T_e of pre-dewatering is substracted from t_1 /T_e is 3 years in the Thorez mine/ and the resulting t_p and the corresponding water level give the initial state of programming.

The second strip $/Z_2-Z_1/$ reaches the observation well in time t_2. By this time, only a permitted water level h_o /about 3.0 m/ can remain in the aquifer. This value h_o above the underlying layer yields the final point of programming. Between the initial and final points a straight-line approximates water level. Programming is to be completed for each observation well and layer.

SUPERVISION OF DEWATERING

The graphical programming line /y, p/, and the actual water level can be compared to supervise the state of dewatering. The difference ΔS_i of programmed and actual levels are calculated for each control point and layer.

$$\pm \Delta S_i = b_{si} - p_{si} \quad [m] \qquad /7/$$

The efficiency of dewatering programming can be measured as

$$\eta_i = \frac{b_{si}}{p_{si}} \cdot 100 \quad [\%] \qquad /8/$$

Values of η_i for many points of a layer inform on possible delay or "over-dewatering". Average η according to layers permits to evaluate the density of wells. Values of ΔS_i and η_i are, however, of static character, not showing any tendency. Consequently, dewatering intensities are compared.

Programmed dewatering intensity is

$$i_p = tg\,\alpha_p = \frac{D}{T_v} \quad [cm/day] \qquad /9/$$

Actual intensity is, after linear fitting:

$$i_b = tg\,\alpha_b = \frac{\Delta s}{\Delta t} \quad [cm/day] \qquad /10/$$

The ratio of intenzities informs on the tendency of the process.

Mapping of control data $/\Delta S_i,\ \eta_i,\ i_b/i_p/$ may contribute to process control aiming at minimizing the difference between planned and actual dewatering. Control possibilities are: changing of pumping rate, areal pumping distribution, pumping network, dewatering time.

Only properly scheduled and systematically supervised dewatering system can lead to an economic optimum and to sufficient safety.

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List of Figures

Fig. 1. Cross-section of intermediate layer dewatering

1-2-3-4	aquifers to be drained
5	intermediate layer
6	inpermeable layer
7	coal seam
8	planned section of the mine
9	pumped triggering well
10	pumped terminal well
11	intermediate well
12	intermediate terminal well
$S_1 \ldots S_5$	drawdown
R_k	radius of the cone of depression for intermediate well
ΔS_4	drawdown left
h_o	piezometric head left
h_n	drainage head
R_n	radius of the cone of depression for the triggering well
L	distance between wells

Fig. 2. Alternatives of well network

8	mining boundary
9	pumped triggering well
10	pumped terminal well
11	intermediate well
12	intermediate terminal well
13	pumped well
Z	advancing mining front

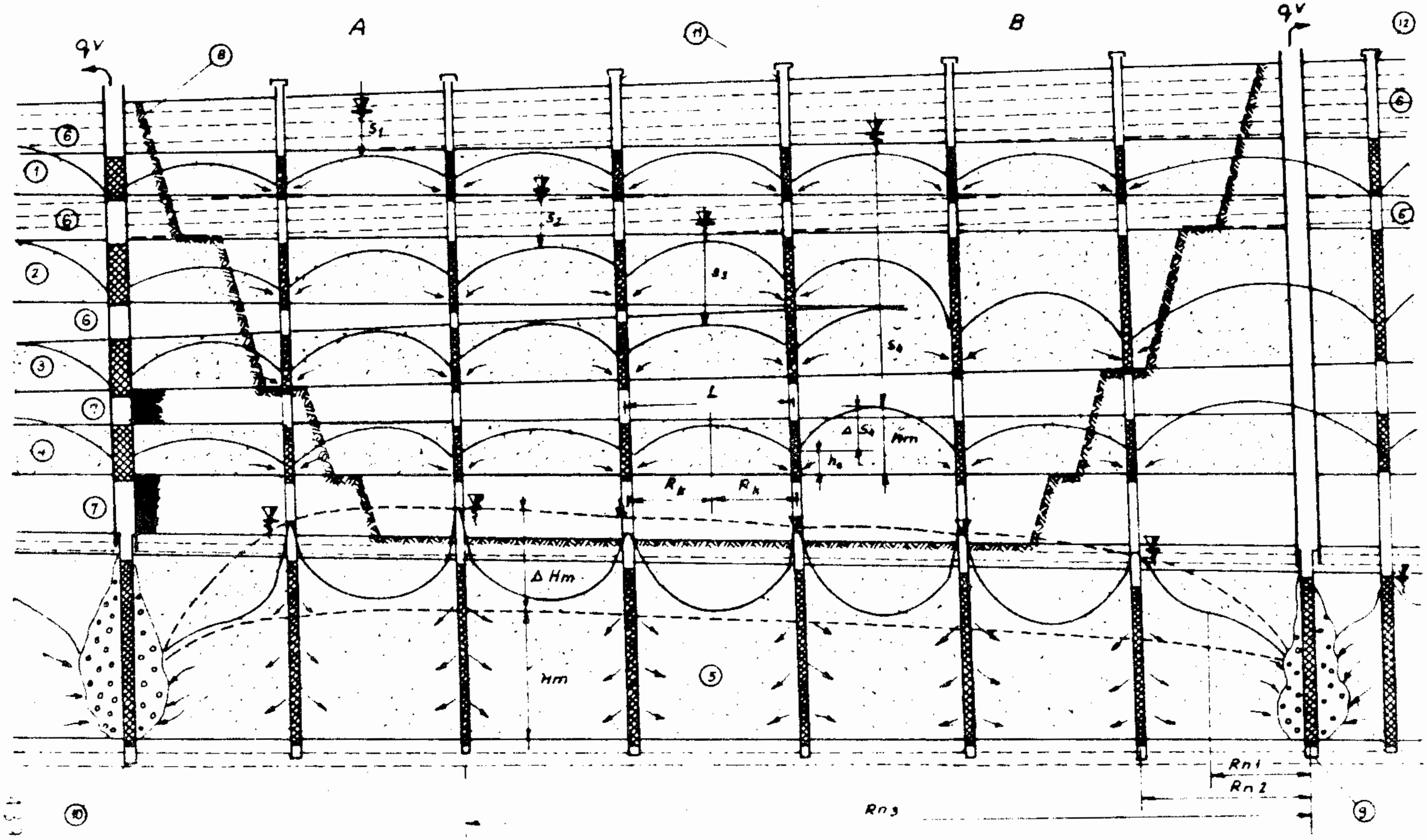
Fig. 3. Scheme of step-by-step dewatering

14	short intermediate well

Fig. 4. Dewatering programming

Z	vertical scale
$Z_o \ldots Z_3$	mining levels
/Z, t/	time diagram of mining
F	section of observation well
A	aquifer to be drained
B	basic line
/y, t/	water level diagram
t_n	time
t_o	start of water level observation
t_p	time of programming
t_i	time of supervision
t_1, t_2	time of mining fronts arriving to the observation well
T_e	period of pre-dewatering /3 years/
T_v	programmed dewatering time
h_o	planned head left
D_o	programmed total drawdown

/y, p/	programmed dewatering
P_s	programmed drawdown in t_i
b_s	actual drawdown in t
ΔS_i	drawdown difference in t
α_p	angle of programmed dewatering
α_b	angle of actual dewatering
IF	provisional observation well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S_1
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S_3
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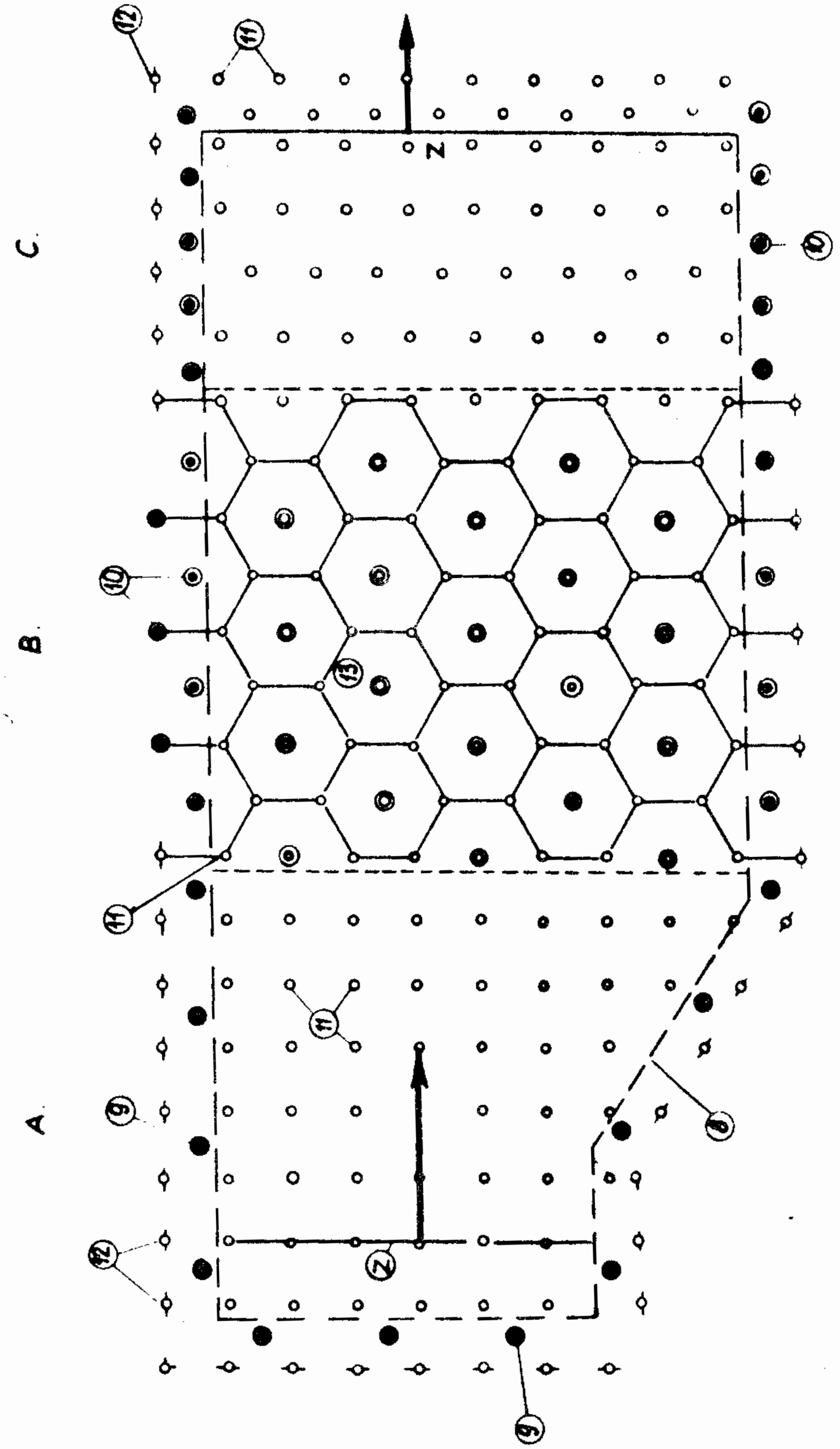
1. ábra Fig. 1.



2. ábra Fig. 2.

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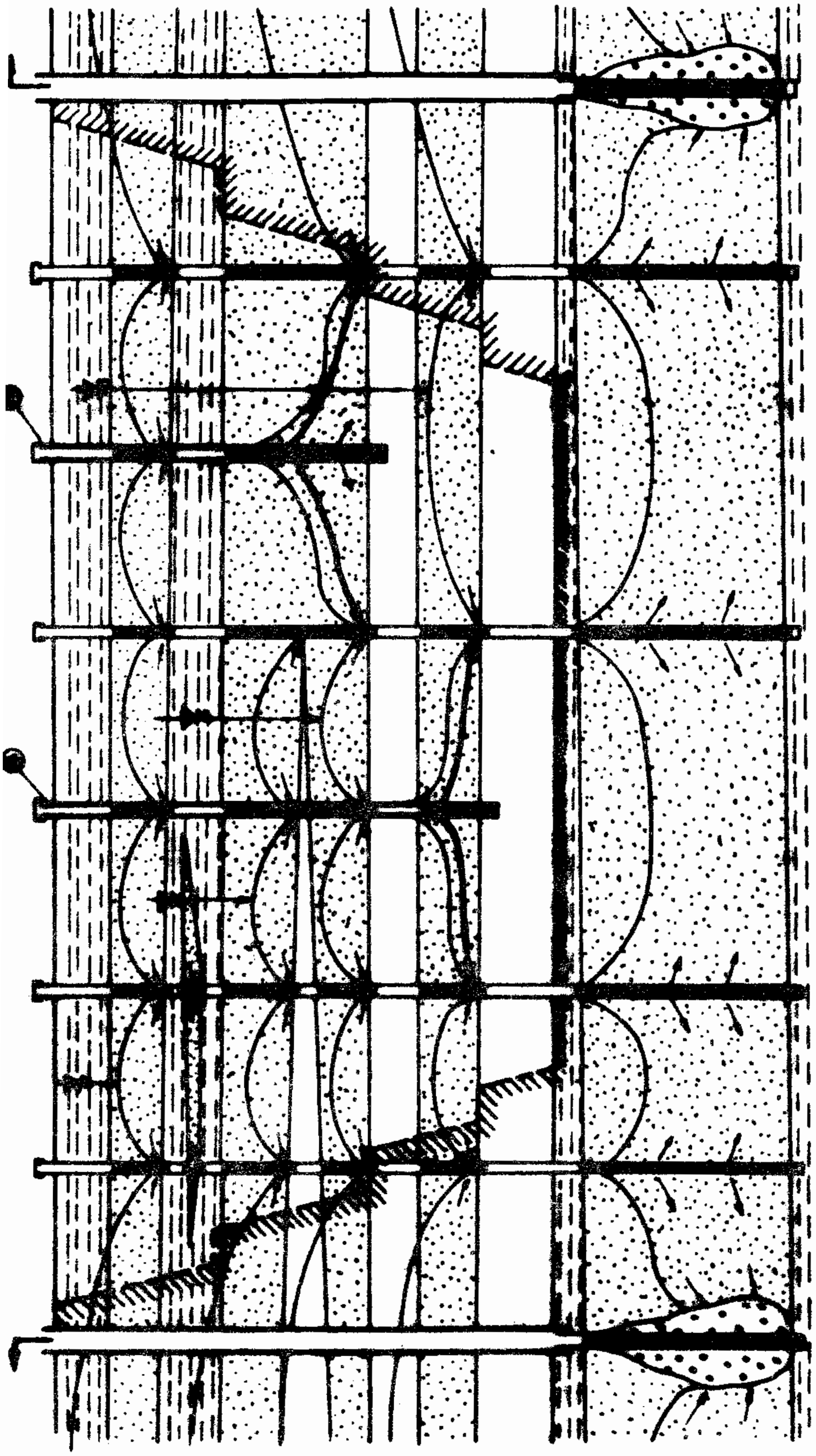

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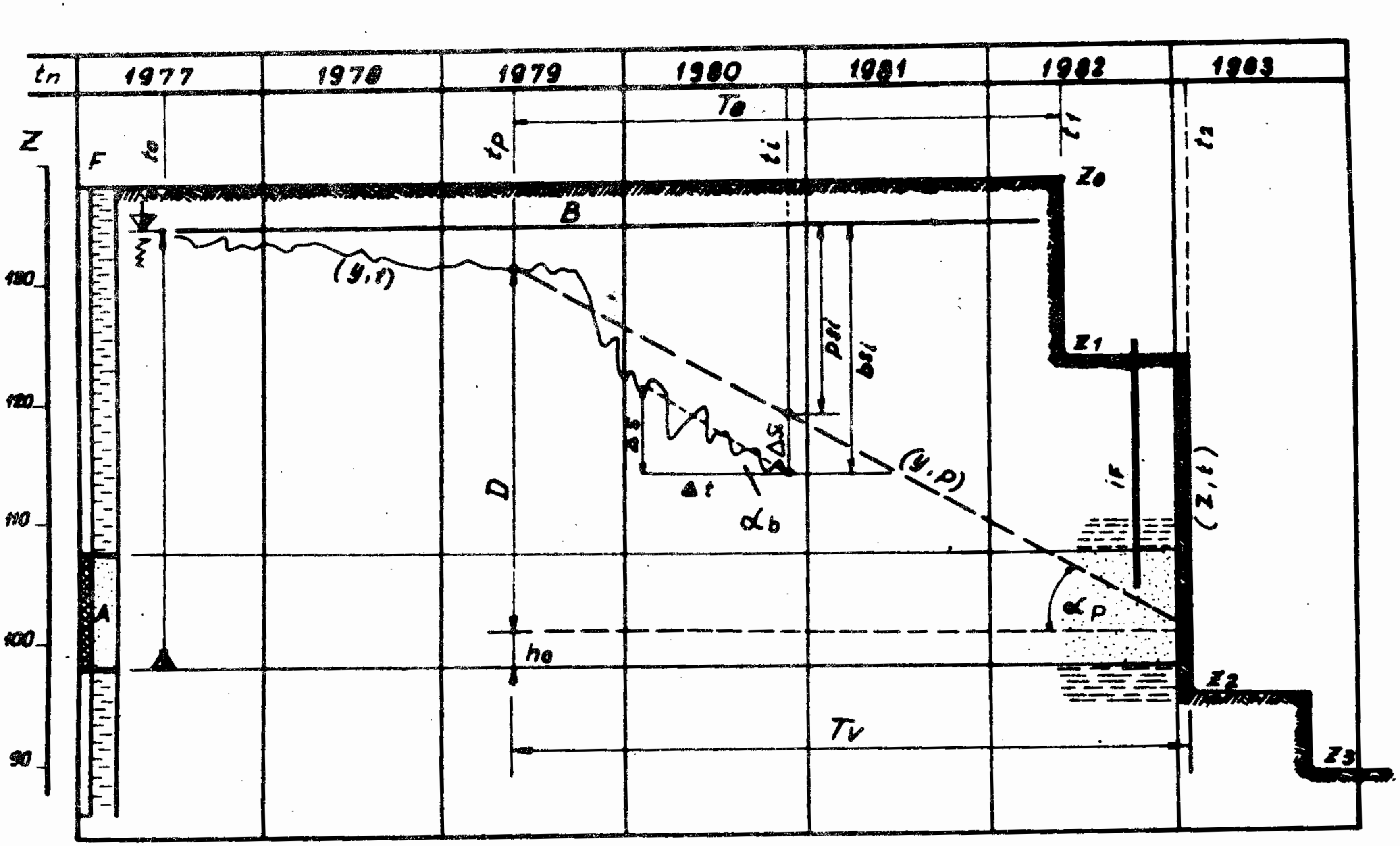
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Z3
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4. ábra Fig. 4.