SURFACE SUBSIDENCE DUE TO WATER LEVEL REDUCTION IN THOREZ OPENCAST MINE

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Working technology in the Thorez opencast mine requires a previous drainage or water level reduction. The pre-dranaige brings about surface movements in the opencast mine and in its wider surroundings. Surface movements are time-dependent processes because of the rheological properties of water reservoir rocks and the time-dependent process of water level reduction.

The study determines the surface subsidence as a funtion of time by theoretical methods taking into account the rheological properties of the water reservoir rocks and the rate of dranaige. The theoretical results are compared with data obtained from in-situ measurements.

The theoretical investigations provide results to be used directly in practice because measurement data reflect only cetain periods of the process that started in 1960 while the measurements have only been carried out since 1973. Around some of the villages in the affected area measurements were performed only during the final period of the dranaige while in some cases the first part of the process was measured.

The study determines the surface subsidence as a function of time and its main parameters for villages Abasár, Visonta, Halmajugra, Detk and Ludas.

1. INTRODUCTION

The coal seams worked in the Thorez opencast mine form the upper part of a sedimentary formation increasing in thickness form the foot of the Mátra mountains towards the Plain. This formation is composed of loose deposits, sands, clays and lignite seams. The seams dip with an angle of inclination of 2-3° towards SE. Sand and sandy layers between the lignite seams store water, the thickness of the aquiferous layers increasing towards SE.

The opencast mining technology uses advancing fronts for removing the overburden and forwinning the coal seams. This technology of working requires a previous dranaige or water level reduction carried out with intermediate layer drainage advancing parallelly to the front. The pre-drainage brings about surface subsidence in and around the opencast mine. This subsidence is a time-dependent process influenced mainly by the rheological properties of the water reservoir rocks and the rate of water level reduction.

In the affected area systematic measurements of rock movement have been carried out by the experts of the Mátraalja Coal Mines since 1973. Pre-draining the opencast mine, however started in 1960, therefore the measurements reflected the final period of the subsidence process at certain villages while the first period is measured around others. Thus, although numerous measurement data are available, only theoretical investigations can describe the whole subsidence process for many villages. The same refers to the main parameters of subsidence, viz. the year of beginning and the end of the movements, the maximum subsidence velocity and the maximum subsidence.

2. PHYSICAL CAUSES OF SURFACE SUBSIDENCE

Experience tells that ground water drainage brings about surface subsidence prolonged over a considerable period of time. According to the transport theory of physics the physical processes are transport phenomena due to equalization tendencies of the so-called intensive quantites viz, stess, temperature, energy density, mass density etc. These quantities shall now be investigated in greater detail.

The water reservoir porous rock can be regarded as a rock-water system whose phases are in mechanical, thermal and chemical interactions with each other. It is easy to prove that thermal and chemical interactions can be ignored from the point of view of the phenomenon in question and it is obvious that mechanical interactions play a decisive role..

The whole /total/ vertical stress of the water reservoir is determined by the weight of the overburden layers above the water reservoir. The total stress is counterbalanced by the so-called effective stress in the solid structure and by the pore water pressure:

$$\sigma_{z1} = z\varrho g = \sigma'_{z1} + p_1 \qquad /1/$$

ith z thickness of the overburden layers,
ϱ average density of the overburden layers,
g acceleration due to gravity,
σ_{z1} vertical total stress,
σ'_{z1} vertical effective stress,
p_1 pore water pressure.

Expressing the vertical effective stress:

$$\sigma'_{z1} = z\varrho g - p_1$$

The horizontal effective stress for elastic deformations can be written as [3, 4, 5]

$$\sigma'_{x1} = \frac{\sigma'_{z1}}{m-1} = \frac{z\varrho g - p_1}{m-1} = \sigma_{x1} - p_1 \qquad /2/$$

with m Poisson's ratio.

The horizontal total stress becomes

$$\sigma_x = \sigma'_{x1} + p_1 = \frac{z\varrho g - p_1}{m-1} + p_1 = \frac{z\varrho g}{m-1} + p_1\frac{m-2}{m-1} =$$

$$= \frac{\sigma_{z1}}{m-1} + p_1\frac{m-2}{m-1} \qquad /3/$$

and the pore water pressure

$$p_1 = \varrho_w g h \qquad /4/$$

with ϱ_w density of water
h static head of water.

Reduces the static head of water by Δh due to drainage, the pore water pressure decreases by $\Delta p = \varrho_w g \Delta h$.

Since the total vertical stress due to the weight of the overburden layers remains constant, the pore water pressure reduction brings about an increase in the effective stress. Thus, the vertical stresses become after the water level reduction

$$\sigma_{z2} = \sigma_{z1} = z\varrho g \qquad /5/$$

$$\sigma'_{z2} = \sigma_{z2} - p_2 = \sigma_{z2} - (p_1 - \Delta p) = z\varrho g - p_1 + \Delta p = \sigma'_{z1} + \Delta p \qquad /6/$$

The horizontal stresses are after the water level reduction

$$\sigma'_{x2} = \frac{\sigma'_{z2}}{m-1} = \frac{\sigma'_{z1} + \Delta p}{m-1} = \sigma'_{x1} + \frac{\Delta p}{m-1} \qquad /7/$$

$$\sigma_{x2} = \sigma'_{x2} + p_2 = \sigma'_{x2} + (p_1 - \Delta p) = \sigma_{x1} + \frac{m-2}{m-1}\Delta p \qquad /8/$$

and the differences between the stresses after and before water level reduction i.e. the deformational stresses become

$$\Delta\sigma_z = \sigma'_{z2} - \sigma'_{z1} = \Delta p = \varrho_w g \Delta h \qquad /9/$$

$$\Delta\sigma'_x = \sigma'_{x2} - \sigma'_{x1} = \frac{\Delta p}{m-1} = \frac{\varrho_w g \Delta h}{m-1} \qquad /10/$$

The solid structure of the water reservoir rock suffers a deformation due to the stress change i.e. the deformational stresses. It can beeasily proved that this deformation obeys Hooke's law because of the elastic state. Since in the co-ordinate system of Fig. 1 $\varepsilon_x = \varepsilon_y = 0$ and $\Delta\sigma'_x = \Delta\sigma'_y$, the vertical deformation of the water reservoir rock is

$$\varepsilon_z = \frac{\Delta h \varrho_w g}{E} \, \frac{m(m-1)-2}{m-1} \qquad /11/$$

with E Young's modulus.

This expression also means that if m = 2 i.e. the material does not change its volume, no vertical deformation takes place, $\varepsilon_z = 0$ because $\varepsilon_x = \varepsilon_y = 0$.

In loose aquiferous deposits viz. sand and clay Young's modulus is not constant but linearly increases with increasing layer depth. It has proved [1, 3, 4, 5, 6] that

$$E = \frac{(m-1)m-2}{(m-1)m}(A+Bz) \qquad /12/$$

with A and B constants.

For materials of constant volume $A = \infty$.

Using these results the vertical deformation can be expressed as

$$\varepsilon_z = \frac{\Delta h \gamma_w g}{A+Bz} \qquad /13/$$

The surface subsidence due to the compression of the water reservoir layer is

$$w = \int_{z_1}^{z_2} \varepsilon_z dz = \frac{\Delta h \gamma_w g}{B} \ln \frac{A+Bz_2}{A+Bz_1} \qquad /14/$$

3. SURFACE SUBSIDENCE AS A FUNCTION OF TIME

In soil mechanics various theories of consolidation are known [1] . These regard, however, the case when the aquiferous rock layer is exposed to an outside load which increases both the total and effective stresses and compression proceeds with the rate of the extrusion of water from the pores. In our case is, however, the situation different therefore the theories of consolidation developed in soil mechanics cannot be applied to describing the process of surface subsidence.

The rheological behaviour of the solid structure of rocks can be described by Poyting-Thomson's model with a good approximation whose equation for uniaxial state of stress is [2]

$$\sigma = E\varepsilon + \lambda \frac{d\varepsilon}{dt} + \eta \frac{d\sigma}{dt} \qquad /15/$$

with σ normal stress,
ε deformation,
E Young's modulus,
t time,
λ linear coefficient of viscosity,
η constant of relaxation.

This model takes account of the creeping properties and relaxation of rocks. Creeping properties express the fact that deformations due to a certain load develop with a delay. Relaxation means the stress reduction at constant deformations. Because displacements and deformations will be analysed in our further investigations, initial and boundary conditions will also be expressed in terms of these quantities. Relaxation of stresses is of no major importance in this case therefore $\eta = 0$ can be assumed, and

$$\sigma = E\varepsilon + \lambda \frac{d\varepsilon}{dt} \qquad /16/$$

being the basic equation of Kelvin's model will be used.
Rearranging

$$\frac{\sigma(t)}{E} = \varepsilon(t) + \frac{\lambda}{E}\,\frac{d\varepsilon(t)}{dt} \qquad /17/$$

and substituting $\frac{\sigma(t)}{E} = \varepsilon_0(t)$, we obtain

$$\frac{d\varepsilon(t)}{dt} = \frac{E}{\lambda}\left[\varepsilon_0(t) - \varepsilon(t)\right] \qquad /18/$$

where $\varepsilon_0(t)$ denotes the deformation at instant t without rheological effect.

Since the vertical displacement is calculated as the integral of the vertical deformation, it can be written that

$$\frac{dw(t)}{dt} = \frac{E}{\lambda}\left[w_0(t) - w(t)\right] \qquad /19/$$

This equation has provided good results for describing the process of surface subsidence of areas above mining activities [7, 8] . For $w_o(t)$ = constant, with that initial conditions t = 0 and w = 0, the solution of the differential equation i.e. the subsidence as a function of time becomes

$$w = w_0\left(1 - e^{-\frac{E}{\lambda}t}\right) \qquad /20/$$

This equation can be also used to describing the process of water level reduction as a function of time:

$$\frac{d\Delta h(t)}{dt} = C[\Delta h_0 - \Delta h(t)] \qquad /21/$$

At a constant rate of water output Δh_o = constant. Using this and initial conditions t = 0, the process of water level reduction can be written as

$$\Delta h(t) = \Delta h_0\left(1 - e^{-Ct}\right) \qquad /22/$$

with C constant depending on the permeability of the aquiferous layer, teh output of the drainage, the pattern of the dewatering wells etc. and being proportional to the rate of water level reduction.

Hence

$$w_0(t) = \overline{w}_0\left(1 - e^{-Ct}\right) \qquad /23/$$

The differential equation of the process of surface subsidence can now be written:

$$\frac{dw(t)}{dt} = \frac{E}{\lambda}\left[\overline{w}_0\left(1 - e^{-Ct}\right) - w(t)\right] \qquad /24/$$

The solution of the differential equation with initial condition t = 0, w = 0 i.e. the function subsidence time is

$$w(t)=\bar{w}_0\left[1-\frac{1}{\frac{C\lambda}{E}-1}\left(\frac{C\lambda}{E}\,e^{-\frac{E}{\lambda}t}-e^{-Ct}\right)\right] \qquad /25/$$

with $\bar{w}_0$ surface subsidence at instant $t=\infty$.
If the water level reduction is infinitely rapid i.e. $C=\infty$ then

$$w(t)=\bar{w}_0\left(1-e^{-\frac{E}{\lambda}t}\right) \qquad /26/$$

If the rate of water level reduction is low i.e. $C \to 0$ then

$$w(t)=\bar{w}_0\left(1-e^{-Ct}\right) \qquad /27/$$

which means that the surface subsidence proceeds with the rate of water level reduction. If $C\lambda/E = 1$ holds a special case is met. Now

$$w(t)=\bar{w}_0\left(1-e^{-Ct}\right) \qquad /28/$$

i.e. surface subsidence proceeds also in this case with the rate of water level reduction.

From these results the conclusion can be drawn that for a water level reduction characterized by

$C > E/\lambda$ /type I/

$$w(t)=\bar{w}_0\left[1-\frac{1}{\frac{C\lambda}{E}-1}\left(\frac{C\lambda}{E}\,e^{\frac{E}{\lambda}t}-e^{-Ct}\right)\right] \qquad /29/$$

holds and for $C = E/\lambda$ /type II/

$$w(t)=\bar{w}_0\left(1-e^{-Ct}\right) \qquad /30/$$

is valid. The subsidence velocity becomes at $C \lessgtr E/\lambda$

$$v(t) = \frac{dw}{dt} = \bar{w}_o C e^{-Ct} \qquad /31/$$

and at $C > E/\lambda$

$$v(t) = \frac{dw}{dt} = \frac{\bar{w}_o C}{\frac{C\lambda}{E} - 1}\left(e^{-\frac{E}{\lambda}t} - e^{-Ct}\right) \qquad /32/$$

At instant t = 0 v = $\bar{w}_o C$ holds in the previous case and v = 0 in the latter case.
The maximum subsidence velocity is experienced at instant

$$t_0 = \frac{\ln \frac{C\lambda}{E}}{C - \frac{E}{\lambda}} \; ; \; \frac{C\lambda}{E} > 1 \qquad /33/$$

And the value of the maximum subsidence velocity becomes

$$v_{max} = \frac{\bar{w}_o C}{\frac{C\lambda}{E} - 1}\left(\frac{C\lambda}{E}\right)^{\frac{1}{1-\frac{C}{E}}} - \left(\frac{C\lambda}{E}\right)^{-\frac{1}{1-\frac{E}{C\lambda}}} ;$$

$$\frac{C\lambda}{E} > 1 \qquad /34/$$

If $C = E/\lambda$ then $v_{max} = \bar{w}\, C$. The subsidence at the point of inflexion $/t = t_o/$ is

$$w(t_0) = \bar{w}_o \left\{ 1 - \frac{1}{\frac{C\lambda}{E} - 1}\left[\left(\frac{C\lambda}{E}\right)^{-\frac{1}{1-\frac{C\lambda}{E}}+1} - \left(\frac{C\lambda}{E}\right)^{-\frac{1}{1-\frac{E}{C\lambda}}}\right]\right\} \qquad /35/$$

Usings Eqs. /33/, /34/ and /35/ we have

$$\frac{v_{max}}{w(t_o)}\, t_o = \frac{\ln\frac{C\lambda}{E}\left[\left(\frac{C\lambda}{E}\right)^{\frac{1}{1-\frac{C\lambda}{E}}} - \left(\frac{C\lambda}{E}\right)^{-\frac{1}{1-\frac{E}{C\lambda}}}\right]}{\left(1-\frac{E}{C\lambda}\right)\left\{1-\frac{1}{\frac{C\lambda}{E}-1}\left[\left(\frac{C\lambda}{E}\right)^{\frac{1}{1-\frac{C\lambda}{E}}+1} - \left(\frac{C\lambda}{E}\right)^{1-\frac{1}{1-\frac{E}{C\lambda}}}\right]\right\}} \qquad /36/$$

Eq. /36/ enables us to calculate $C\lambda/E$ if v_{max}, $w(t_o)$ and t_o are known and in the next step $C\lambda/E$ and $\bar{w}_o$ can be determined. It shall be noted that t_o i.e. the time of the point of inflexion in the subsidence surve, depends only on rock properties and the rate of drainage and is independent of the value of surface subsidence.

In the affected area the main characteristics of the surface movements are as follows. At Abasár surface subsidence started in 1960, the subsidence velocity reached a maximum of 28 mm/year in 1963. Surface subsidense ceased in 1975 totalling at 224 mm in average. In the northern part of Visonta surface subsidence started in 1961, the subsidence velocity reached a maximum of 36 mm/year in 1964. In 1976 surface subsidence ceased, after reaching 280 mm in average. In the southern part of Halmajugra surface subsidence started in 1973, the subsidence velocity reached a maximum of 9 mm/year in 1976. Surface subsidence can be expected to cease in 1988 with an average total of 100 mm. In the central part of Halmajugra surface subsidence started in 1973, the maximum subsidence velocity, 22 mm/year was experienced in 1976. Surface subsidence can be expected to come to an end in 1988 with an average value of 180 mm. In the northern part of Halmajugra surface subsidence started in 1972, subsidence velocity reached its maximum with 15 mm/year in 1975. Surface subsidence will probably cease in 1987 with an average total of 120 mm. At village Detk surface subsidence started in 1973, the subsidence velocity was at its maximum of 9 mm/year in 1976. The surface subsidence will end predictably in 1988 with an average total of 80 mm. At village Ludas surface subsidence began in 1973, the subsidence velocity had its maximum /10 mm/year/ in 1976. Surface subsidence is expected to end in 1988 reaching a total of 80 mm in average.

4. SURFACE SUBSIDENCE IN THE AREA OF THOREZ OPENCAST MINE

Thorez opencast mine and its surroundings are illustrated in map N°1. A measurement line can be seen near the opencast mine crossing villages Ludas, Detk, Halmajugra, Visonta and Abasár. An evaluation of the measurements about surface subsidence provided the following average data for the area [9] : $C\lambda/E = 2.0$; $C = 0.60$ year^{-1} ; $E = 0.25$ year^{-1} . On substituting these values the function of surface subsidence becomes

$$\frac{w/t/}{w_0} = 1 - 2e^{-0.25\,t} + e^{-0.5\,t}, \quad t\,[\text{year}] \qquad /37/$$

The functions of surface subsidence for the various villages are as follows.

Ludas: t = 0, 1973

$$w/t/ = 80\left(1 - 2e^{-0.25\,t} + e^{-0.5\,t}\right), \text{ mm} \quad t\,[\text{year}] \qquad /38/$$

Detk: t = 0, 1973

$$w/t/ = 80\left(1 - 2e^{-0.25\,t} + e^{-0.5\,t}\right), \text{ mm} \qquad /39/$$

Halmajugra South: t = 0, 1973

$$w/t/ = 100\left(1 - 2e^{-0.25\,t} + e^{-0.5\,t}\right), \text{ mm} \qquad /40/$$

Halmajugra Central: t = 0, 1973

$$w/t/ = 180\left(1 - 2e^{-0.25\,t} + e^{-0.5\,t}\right), \text{ mm} \qquad /41/$$

Halmajugra North: t = 0, 1972

$$w/t/ = 120 \left(1 - 2e^{-0.25\,t} + e^{-0.5\,t} \right), \text{mm} \qquad /42/$$

Visonta North: t = 0, 1961

$$w/t/ = 289 \left(1 - 2e^{-0.25\,t} + e^{-0.5\,t} \right), \text{mm} \qquad /43/$$

Abasár: t = 1960

$$w/t/ = 224 \left(1 - 2e^{-0.25\,t} + e^{-0.5\,t} \right), \text{mm} \qquad /44/$$

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FIGURES

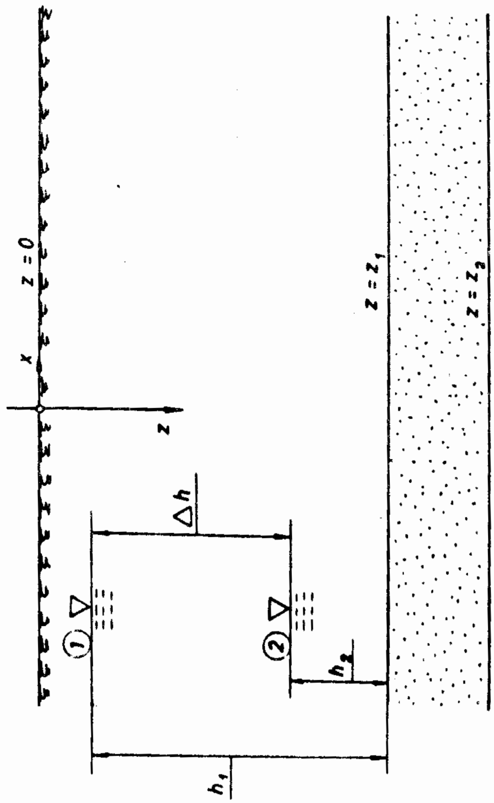
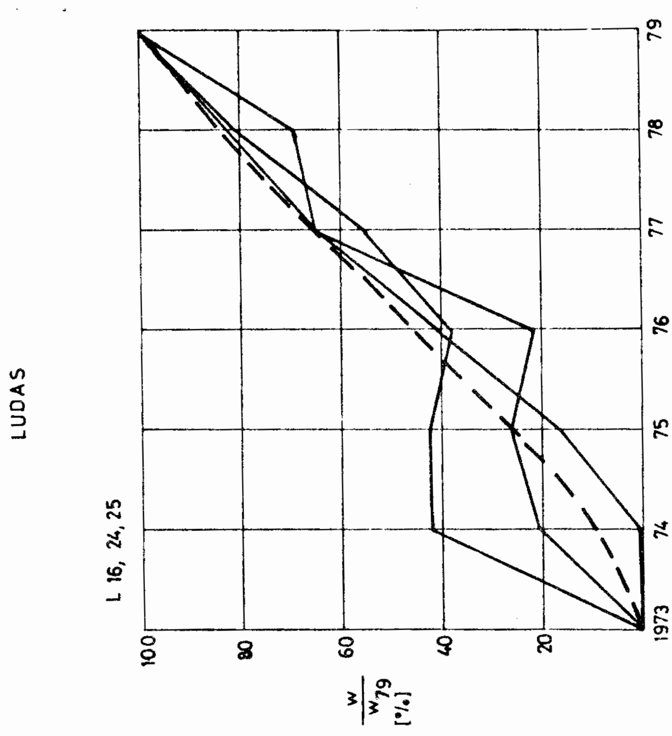


Fig. 1. ábra



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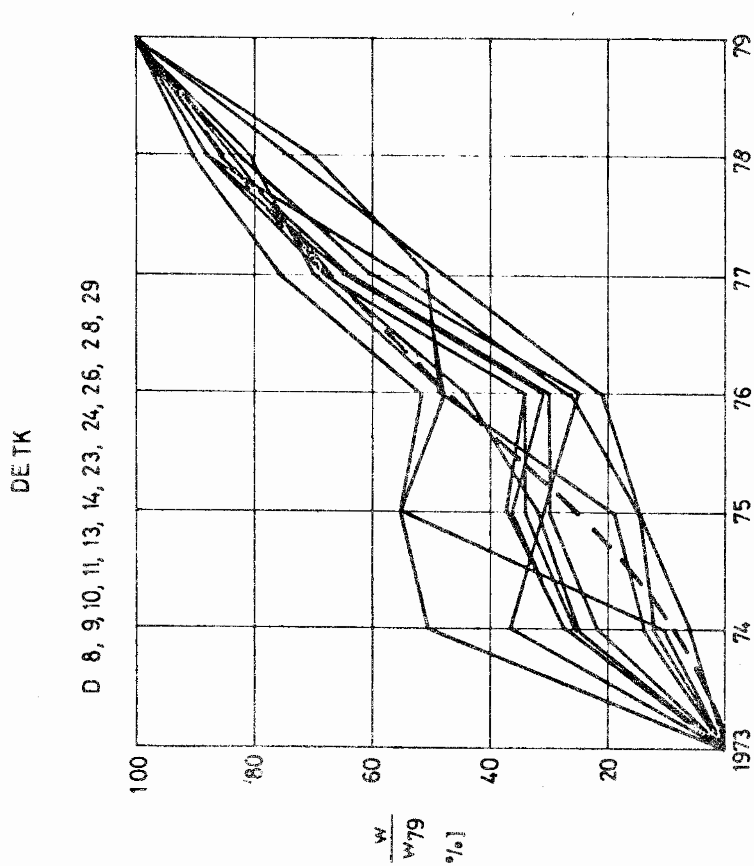
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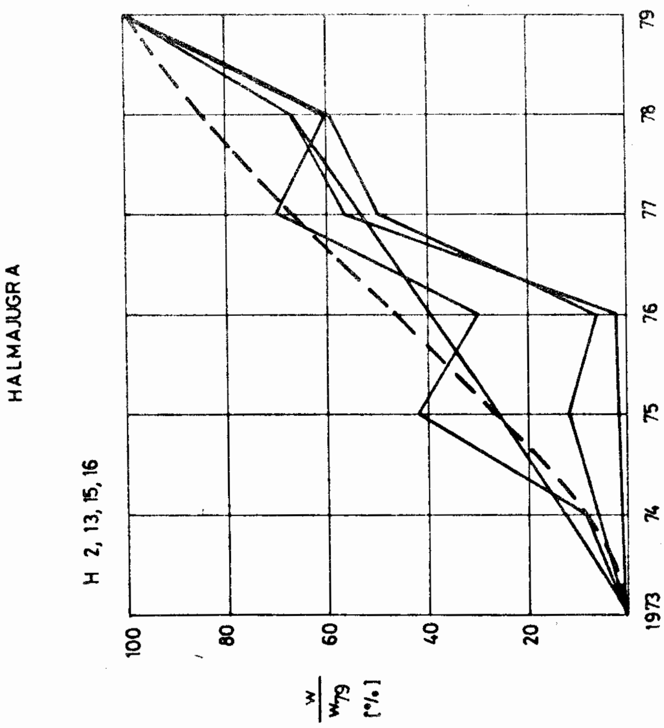

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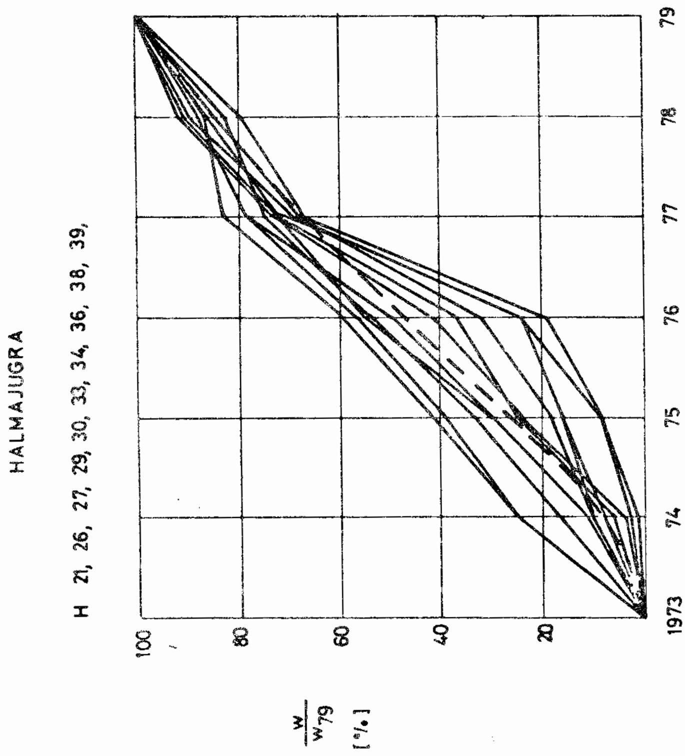
HALMAJUGRA
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Fig. 5. ábra

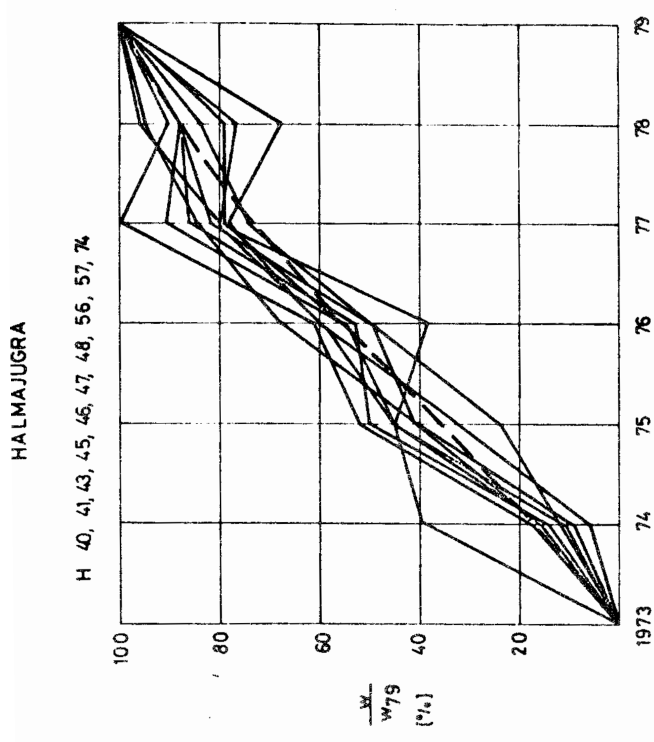
HALMAJUGRA
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Fig. 6. ábra

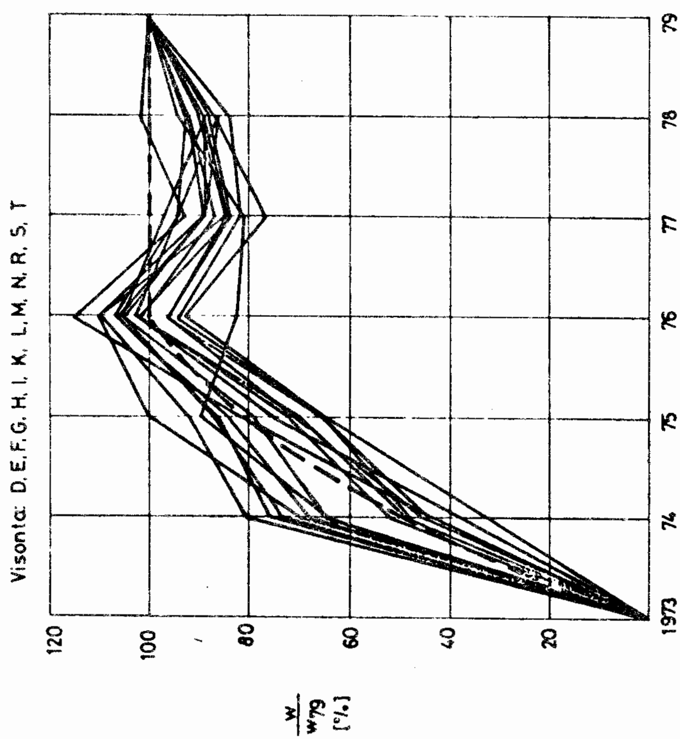
Visonta: D, E, F, G, H, I, K, L, M, N, R, S, T
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Fig. 7. ábra

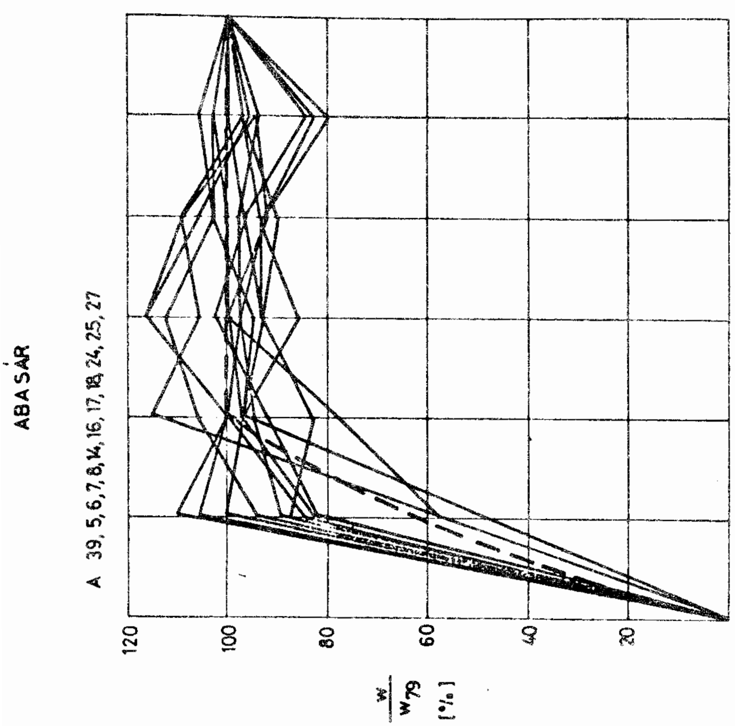
ABASÁR
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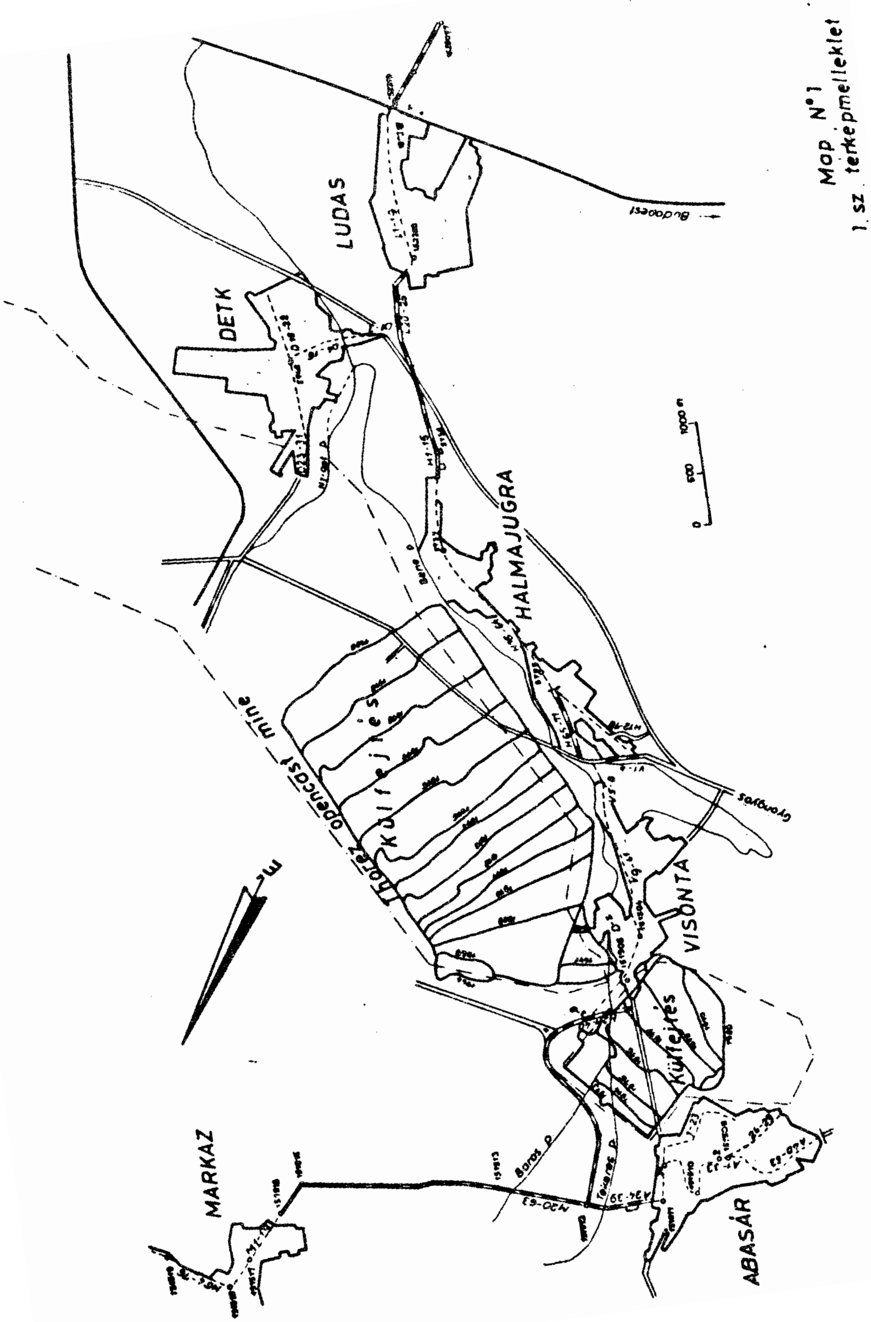
Fig. 8. ábra


Map N°1
1. sz. térképmelléklet
LUDAS
DETK
HALMAJUGRA
VISONTA
ABASÁR
MARKAZ
Thorez opencast mine
Külfejtés
Budapest
Gyöngyös
0 500 1000 m