DETERMINING THE DIMENSIONAL PARAMETERS WHICH CHARACTERISE THE INCLINED SLICES THICK COAL STRATA EXPLOITATION METHODS IN THE JIU VALLEY UNITARY COST PER EXTRACTED COAL TONNE FUNCTION

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Abstract: The decision to apply an exploitation method, regardless of the mineral substance under exploitation, is taken following an analysis of a plethora of geological, technical and economic factors. The present work has proposed to determine the geometric parameters of the inclined slices exploitation method applied in the thick coal strata in the Jiu Valley, in the mining perimeters and the belonging strata zones which allow for its application. The crucial criterion to which attention has been paid when effecting this analysis is the unitary cost of the coal tonne extracted from the coal-face, the work process undertaken in the coal-face being detailed rigorously, the costs thus accrued constituting the basis for the general costs equation. The analyzed technology is classical whereby the work front is cut by way of perforation-explosion, the support of the coal-face is realized with the help of SVJ pillars and GSA beams and the evacuation of the mined coal being done through manual shoveling on the transporter mounted on the coal-face.

Key words: *exploitation method, inclined slices, thick strata, coal-face technologies, work norm, individually supported coal-face, efficiency, unitary cost*.

1. Introduction

The totality of the Jiu Valley basin is affected by a complex tectonic structure, materialised through the presence of a large number of diagonal and longitudinal faults which compartmentalise the deposit in numerous differently sized blocks. As such, when projecting the exploitation methods, mining industry specialists must pay close attention to the restrictions imposed in respect of developing the strata by the existing fault lines.

The inclined slices thick coal strata exploitation method has been used in the Jiu Valley mining basin in almost all of the mining perimeters where the thick 3 and 5 strata quartering conditions so permitted. The application of this method was conditioned by a series of restrictions regarding the stratum and access to technology such as:

- Minimum stratum thickness – 4m;
- Inclination of the stratum – maximum 35 º and in the case of long inclined poles the inclination limit is directed by the available support technology;
- Uniform directional and inclinational development as well as sterile intercalations reduced in numbers and strength;
- The rocks in the direct roof must be soft and predisposed to total collapse.

According to the way in which the preparation works' architecture is conceived, the inclined slices exploitation method can be applied in numerous variants, as follows [3]:

- Variant 1: long directional pillars and executing the preparations works in mullock and the stratum;
- Variant 2: long directional pillars in the stratum and executing the preparation works in the bottom-wall mullock and the stratum;
- Variant 3: long pillars in the inclined stratum and executing the preparation works in the bottom-wall mullock and the stratum;
- Variant 4: long pillars in the inclined stratum and executing the preparation works in the stratum;
- Variant 5: long pillars in the inclined stratum and executing the preparation works in the stratum;

2. Assigning the study object – basal technological unity

The variant subject to analysis in this material is represented in figure 1, variant where the preparation works are executed both in the mullock rocks in the strata bottom-wall and on the strata itself.

The working technology utilised in the coal-face is the classic one where the coal is sliced through perforation-explosion and manual evacuation of the coal, the support of the coal-face being realised with SVJ 3,15m pillars and GSA – 1,25m beams in fields no larger than 0,8m. The coal-face roof is built out of wire mesh with a wire diameter of 5mm, the mesh rolls being stitched together both longitudinally and latitudinally with an anchor wire. Channelling the mining pressure is done through total collapse of the rocks from the direct room. Airing the coal-face is done under the general mine depression. De necessary air debit for each coal-face is established with an airing project done in conformity with technical instructions in respect of work and safety regulations.

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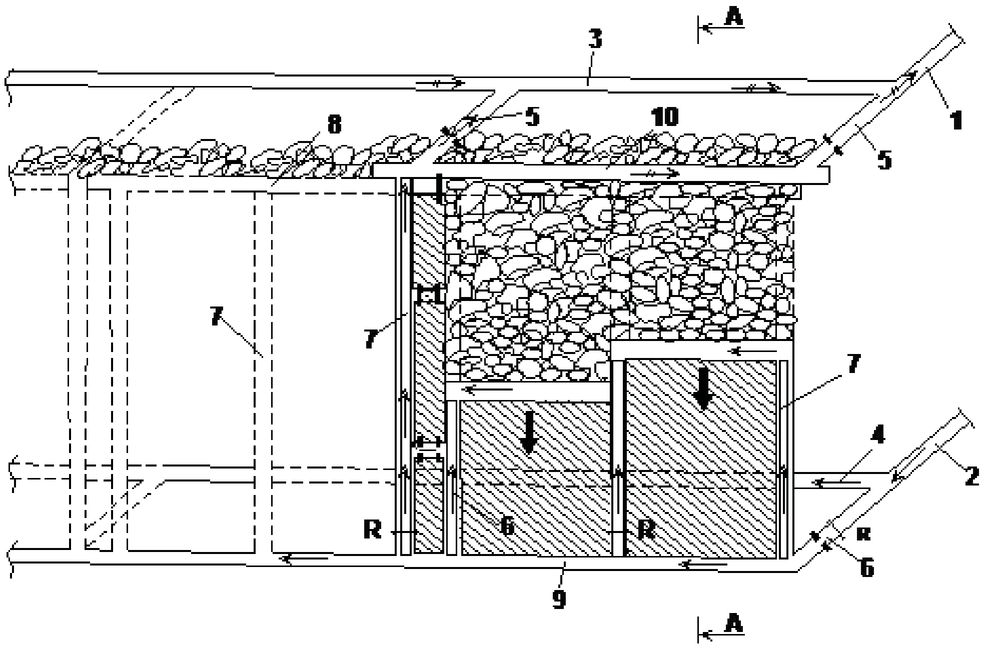

Fig. 1 *Long inclined pillars with executing the preparation works in the bottom-wall and on the stratum exploitation variant*
1,2 – main transversal (block) galleries; 3,4 – top and bottom directional galleries in the stratum bottom-wall; 5,6 – intermediary transversal galleries; 7 – inclined panel contouring plans; 8,9 – slice I directional strata galleries; 10 – slice II direction strata gallery

Having detailed knowledge of the components of the production process allows one to identify all the cost bearing elements, respectively integrating these in a mathematic model which finally leads to a correct choice of the possibly applicable geometric parameters of the exploitation method. During the economic analysis of the production process we have only used directly identified costs, these being shared on each element of the process. The analysis does not include other cost bearing elements that go towards calculating the unitary cost realised at exploitation level, these being integrated in the selling price of the coal tonne.

Gathering and working with the information regarding the production cost as well as utilising them in the management process of the productive activity implies a detailed knowledge of the way in which the activity unfolds in time and space. A correct interpretation of this information and rapid intervention where dysfunctionalities are identified determines obtaining sustainable long-term economic results.

As such, the resulting mathematical model quantifies the productive process that unfolds on the coal-face respectively the modelled unit being ‘the frontal coal-face with long inclination pillars’.

3. Modelling the production process afferent to the inclined slices exploitation method, the long-inclined pillars extracted through perforation-explosion variant, the support being realised with individual metallic frames

3.1. Modelling the costs for the acquisition of digging materials for preparation mining works

In order to execute the preparation mining works in mullock rocks in the strata bottom-wall drawn in the architecture of the inclined slices thick strata exploitation method we are going to use the variant which uses cutting technologies with advancement combines types ATM-50, SANDVIK MR-120, manufactured by Sandvik Mining and Constructions or REMAGAM-50z-w manufactured by Famour Group Poland.

The costs registered with acquiring the digging equipment will be calculated through reporting the entry (acquisition) value to the lifespan of the acquired equipment, the devaluation of the equipment as a result of their use in the production process making its way in the final cost of the extracted tonne of coal from the coal-face.

For calculating the softening of the digging equipment’s value we are going to use the ‘equal norms method’ [1], [8], [9], which characterises the linear system of softening and consists of calculating and using the same softening norm throughout the whole lifespan of the equipment.

This means that the annual softening is equal throughout the whole lifespan of the respective corporeal immobiliser.

The calculus relation for costs accrued with digging materials will be as follows:

$$C_{us} = A_a \cdot T_1 \text{, [lei]} \quad (1)$$

where:

T_1 - the duration of executing the preparation works [years], calculated using:

$$T_1 = T_1^{'} + T_1^{''} = 0{,}008 \cdot \frac{1}{v_s} \cdot \left[l_{ca} + l_{ab} + l_{ca} \cdot h_{ab} \cdot \left(\frac{80}{l_p} + \frac{1}{m} \right) \right] \text{,[yrs]} \quad (2)$$

where:

$T_1^{'}$ – represents the duration of realising the execution of the work on the strata [yrs];

$T_1^{''}$ – represents the duration of realising the works in the bottom-wall. [yrs];

h_{ab} – coal-face height [m];

l_{ca} – represents the length of the coal-face field [m];

l_{ab} – represents the length of the coal-face (stripes), [m];

l_p – represents the length of the panel under exploitation (directional), [m];

m – thickness of the strata, [m];

v_s – execution speed of the preparation mining works, [m/day];

A_a – annual softening, calculated using:

$$A_a = \frac{V_{co}}{d} \text{, [lei/yr]} \quad (3)$$

where:

V_{co} – the entry value of the immobilised active (the advancement combine), [lei/UM];

d- the normal functioning lifespan, [yrs or mths].

The costs accrued with the digging equipment which are to be taken into account in establishing the unitary cost of per extracted tonne are going to be calculated using the following formula:

$$C_{us} = 0{,}008 \cdot \frac{V_{co}}{d} \cdot \frac{1}{v_s} \cdot \left[l_{ca} + l_{ab} + l_{ca} \cdot h_{ab} \cdot \left(\frac{80}{l_p} + \frac{1}{m} \right) \right] \text{,[lei]} \quad (4)$$

3.2. Modelling the costs for realising the preparation works

In order to determine the equation for costs accrued with executing the preparation works necessary for contouring the coal-face we are going to use the network of works found in figure 1.

According to the presented scheme, the network of mining works consists of:

- Transversal block gallery (head), executed in mullock, with length l_{gtbc};
- Transversal block gallery (base), executed in mullock, with length l_{gtbb};
- Directional head gallery (airing) executed in the strata bottom-wall up to the directional limit of the tectonic block, with length l_{gdc};
- Directional base gallery (transport), executed in the strata bottom-wall up to the directional limit of the tectonic block, with length l_{gdb};
- Intermediary transversal head galleries, executed at distances of 100-120m, with length l_{gtic};
- Intermediary transversal base galleries, executed at distances of 100-120m, with length l_{gtib};
- Inclined coal-face contouring plane (base), executed on the strata with length l_{ca};
- Inclined coal-face contouring plane (head), executed on the strata with length l_{ca};
- Directional base gallery, executed at the level of each exploited slice, with length $l_{gdb} \approx l_p$;
- Directional head gallery, executed at the level of each exploited slice, with length $l_{gdc} \approx l_p$;
- Attack pre-coal-face which connects the two inclined transport and airing planes, with length l_{ab}.

The works will be executed using a typified mining profile GDM -11,0 in mullock, while on the strata the used profile will be type GDM 10,0 the works being executed using an advancement combine.

The support for the works will be provided with sliding metallic arcs type SG-23, mounted in fields 0,8m long. Bandaging the extrados support will be done with wooden bandages in the ceiling, the lateral walls being bandaged with metallic mesh. Transporting the unearthed material will be done with bladed transporters.

Airing the mining works will be done with partial airing systems dimensioned in order to assure the parameters required by health and safety regulations are met. On perforation, these are to be placed underneath the general depression of the mine.

The attack pre-coal-face will be executed at a profile of 7,9m^2, its support being realised with hydraulic SVJ 3,15m pillars and two metallic articulated GSA 1,25m beams, in fields of 0,8m. Both the ceiling and the lateral walls are to be bandaged with metallic mesh.

In order to determine the relation for costs accrued with preparation works we will consider the following:

- The preparation works performed in mullock, in the strata bottom-wall will serve to extract the whole reserve quartered in the block, being active up until when the last slice is extracted;
- The costs accrued with the execution of the works which serve the whole floor are to be proportionally spread on each coal-face and slice, the number of exploited slices being calculated using:

$$n_f = \frac{m}{h_{ab}}, \quad (5)$$

where:

m - represents the thickness of the strata, [m];

h_{ab} – represents the height of the coal-face, [m].

- The number of intermediary transversal galleries which connect the preparation works executed on the strata and the ones in the mullock is to be calculated by reporting the directional length of the block to the distance between the galleries, this always being a whole number;

$$n_{gti} = \frac{l_p}{120}, \qquad (6)$$

- The length of the intermediary transversal galleries and the transversal block galleries will be 30m maximum.

Considering the aforementioned restrictions, the relationship of the costs with the preparation works for each coal-face will be as follows:

$$C_{lp} = 2\cdot l_{ca}\cdot k_{gc} + 2\cdot l_{ab}\cdot k_{gc} + \frac{1}{60}\cdot l_{gti}\cdot l_{ab}\cdot\frac{h_{ab}}{m}\cdot k_{gc} + 2\cdot l_{gtb}\cdot\frac{l_{ab}}{l_p}\cdot\frac{h_{ab}}{m}\cdot k_{gs} + 2\cdot l_{ab}\cdot\frac{h_{ab}}{m}\cdot k_{gs} + l_{ab}\cdot k_{sa} = \qquad (7)$$
$$2\cdot l_{ca}\cdot k_{gc} + l_{ab}\cdot\left(2\cdot k_{gc} + k_{sa}\right) + l_{ab}\cdot\frac{h_{ab}}{m}\cdot\left(0{,}5\cdot k_{gc} + 100\cdot\frac{1}{l_p}\cdot k_{gs} + 2\cdot k_{gs}\right)\ [lei]$$

where:

k_{gs} – the cost of a gallery meter executed in mullock, [lei/m];

k_{gc} – the cost of a gallery meter executed in coal, [lei/m];

l_{gti}, l_{gtb}, - the length of the intermediary transversal gallery and the transversal block gallery, [m];

l_{ca} – length of the coal-face field, [m];

l_{ab} – length of the coal-face front, [m];

h_{ab} – height of the coal-face, [m].

3.3. Modelling the support costs of the preparation works

The support costs of the preparation works which are executed for exploiting the reserve in an exploitation block must be divided into two categories, as follows: costs related to the support of the preparation works executed on the strata and which serve the slice currently under exploitation and costs related to the support of the preparation works in mullock and whose functionality must be maintained until the whole reserve has been exploited. The differentiation between the two types of costs is made mainly by the lifespan of the works as well as their placement in the coal-face's area of influence. If the works executed in mullock are guarded from the direct influence of the leaning pressure developed by the works in the coal-face, the works in the slice under exploitation can suffer deformities and section reductions, requiring intervention works for maintaining the free surface and functionality, thus increasing the support costs. The analysis of the costs effected for supporting the mining preparation works in mining exploitation, analysis which took a considerably large number of years, led to the establishing of a 10-15% of the initial value of the preparation works as being sufficient to cover the works effected for supporting these over a year.

As such, the relation which determines the costs accrued with supporting the mining works will be as follows:

$$C_{il} = \xi\cdot\sum_{1}^{n} C_{lp}\cdot T_i\ \text{[lei]} \qquad (8)$$

where:

ξ – represents the annual share coefficient of support costs from the total preparation work costs, (10-15%);

C_p – the costs for digging each type of preparation mine work, executed on the strata or in mullock, (lei);

T_i – support time, (yrs);

In order to determine the value of these expenses it is necessary to determine the support time required for the quantity of mining works for each coal-face in turn out of the total of mining works executed to prepare the exploitation floor.

As such, the support time of the works is determined by the exploitation time of the coal-face and is to be determined using the following relation:

$$T_î = \frac{T_{ex}}{2} = \frac{l_{ca}}{2\cdot N_z\cdot 12\cdot v_{ab}} = \frac{l_{ca}}{492{,}48\cdot v_{ab}}\ \text{[yrs]} \qquad (9)$$

where:

T_{ex} – exploitation time of the existent reserve in the coal-face, [yrs].

N_z = 20,52 – average working days/month

v_{ab} – daily speed of advancing the coal-face front, [m/day].

The functionality of intermediary transversal galleries, of transversal galleries and directional galleries executed in the bottom-wall must be maintained up until the whole reserve in the floor has been exploited.

Introducing relations [7] and [9] in relation [8] we obtain the relation which determines the costs effected for supporting the preparation works for the working coal-face, which is as follows:

$$\sum C_{il} = \xi\cdot\frac{1}{v_{ab}}\cdot\frac{1}{492{,}48}\cdot\left[\begin{array}{l} 2\cdot l_{ca}^2\cdot k_{gc} + l_{ab}\cdot l_{ca}\cdot\left(2\cdot k_{gc} + k_{sa}\right) \\ + l_{ab}\cdot l_{ca}\cdot\frac{h_{ab}}{m}\cdot\left(0{,}5\cdot k_{gc} + \frac{100}{l_p}\cdot k_{gs} + 2\cdot k_{gs}\right)\end{array}\right]\ \text{[lei]} \qquad (10)$$

where the lateral indices have the aforementioned significations.

3.4. Modelling the acquisition costs for support, transport and cutting equipment

Depending on the deposit conditions as well as the level of development of the mining technique, at a certain point in time an exploitation method can be applied in a certain variant. Depending on the applied technological variant one establishes the necessary equipment in the work front for reaching the useful mineral substance extraction process. In the analysed scenario cutting the coal is done through perforation-explosion, and the support of the coal-face is realised through utilising individual metallic support consisting of hydraulic pillars and articulated beams. The transport of useful mineral substance is realised through the intermedium of bladed transporters up to the main flow of transport. As such, in the coal-face front one can observe the presence of the following pieces of equipment:

- Perforation and cutting equipment: rotative perforators type MVK-03, percussing perforators type WVP-22 and coal-face hammers type CA-14 or similar;
- Coal-face support equipment: SVJ-3,15m or 2,5m pillars, GSA-1,25m beams and the hydraulic aggregate for providing the hydraulic agent necessary for tensing the pillars;
- Production transport equipment: bladed transporters type TR-3, TR-4 or TR-5.

The costs effected with acquiring the equipment will be calculated through allocating a specific share of the entry value of the fixed means used in the production process reported to their economical lifespan.

From an economic view-point, the amortisation represents the process whereby the entry value of the immobiliser (the fixed means) is shared across its whole lifespan.

The general relation of costs effected with acquiring the equipment is as follows:

$$C_{ut} = \sum A_a \cdot T_{ex} \text{ [lei]} \quad (11)$$

where:

A_a – represents the annual amortisation, calculated using:

$$A_a = \frac{V_i}{D}, \text{ [lei/yr]} \quad (12)$$

where:

V_i – the entry value of the acquired fixed means, [lei/each];

D – lifespan of the fixed means (equipment) [yrs];

$$C_{ut} = \sum_{i=1}^{n} \frac{V_i}{D_i} \cdot T_{ex} = \left(\frac{V_{iup}}{D_{iup}} + \frac{V_{ius}}{D_{ius}} + \frac{V_{iut}}{D_{iut}} \right) \cdot T_{ex} \text{ [lei]} \quad (13)$$

The amortisation ratio for cutting and perforation equipment is calculated using:

$$A_{up} = \frac{V_{pr} \cdot n_{pr}}{D_1} + \frac{V_{pp} \cdot n_{pp}}{D_1} + \frac{V_{ca} \cdot n_{ca}}{D_1} \text{ [lei/an]} \quad (14)$$

where:

V_{pr} – represents the entry value of rotative perforators, [lei/each];

V_{pp} – represents the entry value of percussing perforators, [lei/each];

V_{ca} – represents the entry value of coal-face hammers, [lei/each];

n_{pr}, n_{pp}, n_{ca} – represents the number of rotative and percussing perforators and coal-face hammers in the work place, [pieces];

D_1 – 4 years, the amortisation period afferent to perforation equipment, according to the Catalogue of Classification of Fixed Means Utilised in Economy [12].

The relation for calculating the annual amortisation ratio for transport equipment is as follows:

$$A_{ut} = \frac{V_{tab} \cdot n_{tab}}{D_2} + \frac{V_{tpl} \cdot n_{tpl}}{D_2} + \frac{V_{tgd} \cdot n_{td}}{D_2} = \frac{V_{tab} \cdot n_{tab}}{D_2} + \frac{V_{tpl}}{D_2} \cdot \frac{l_{ca}}{60} + \frac{V_{tgd}}{D_2} \cdot \frac{l_p}{60} \text{ [lei/yr]} \quad (15)$$

where:

V_{tab} – represents the entry value of coal-face transporters, [lei/each];

V_{tpl} – represents the entry value of inclined plane transporters, [lei/each];

V_{tgd} – represents the entry value of transporters mounted on the directional gallery, [lei/each];

n_{tab} – the number of transporters on the coal-face, regularly in the coal-face there is only one transporter regardless of its length in order to simplify the transporter's motion operations and to direct the mining pressure. In order to prevent any dysfunctionalities that may occur the power of its motor is increased.

n_{tgd} – the number of transporters on the directional gallery;

D_2 – 4 years, the amortisation period for transport equipment, according to [12].

The amortisation ratio afferent to support equipment is calculated using the following:

$$A_{us} = \frac{V_{us} \cdot n_{cs}}{D_3} + \frac{V_{ah}}{D_3} = \frac{V_{us}}{D_3} \cdot \frac{l_{ab}}{d_s} + \frac{V_{ah}}{D_{ah}} \text{ [lei/yr]} \quad (16)$$

where:

V_{us} – the entry value of a support frame, [lei/each]. A support frame is comprised of 3 GSA-1,25m beams and 4 SVJ-3,15m pillars.

n_{cs} – represents the number of support frames mounted on the coal faces and is calculated as a fraction between the coal-face's length and the arming step established through arming monography.

Albeit the inventory value of the components for support frames is lower than the value which allows classifying them in the fixed means category, these are to be analysed as fixed means being registered in the accounting evidence of mining units as inventory items of a fixed means nature, the full provisions of the Fiscal Code being applied in respect of amortisation.

V_{ah} – the entry value of hydraulic aggregate, [lei/each];

D_{ah} – 12 years – the lifespan of a fixed mean, [years];

The exploitation time of a coal-face field is calculated using the following:

$$T_{ex} = \frac{l_{ca}}{N_z \cdot v_{ab}} = \frac{l_{ca}}{246{,}24 \cdot v_z} \text{ [yrs]} \qquad (17)$$

where:
l_{ca} – the length of the coal-face field, [m];
N_z – 246,24 the number of working days each year (averaged over the last 4 years);
v_z – the daily speed at which the coal-face front works advance, [m/day];

The finalised relation for costs effected for equipment acquisition is as follows:

$$C_{ut} = \left[\begin{array}{l} \left(\frac{V_{pr} \cdot n_{pr}}{D_1} + \frac{V_{pp} \cdot n_{pp}}{D_1} + \frac{V_{ca} \cdot n_{ca}}{D_1} \right) + \\ \left(\frac{V_{tab} \cdot n_{tab}}{D_2} + \frac{V_{tpr}}{D_2} \frac{l_{ca}}{60} + \frac{V_{tgd}}{D_2} \frac{l_p}{120} \right) + \left(\frac{V_{us}}{D_3} \frac{l_{ab}}{d_s} + \frac{V_{ah}}{D_{ah}} \right) \end{array} \right] \frac{1}{v_{ab}} \frac{l_{ca}}{246{,}24} \text{ [lei]} \qquad (18)$$

3.5. Modelling the costs for coal-face works

Exploitation costs represent the resources consumption effected in order to realise the activity objective [34], in our case the unity of the end product is represented by the extracted tonne of coal. Included in this category are the following: prime and consumable materials, electric power and water, fuels, wages and related costs, taxes and assimilated costs.

Grouping the costs for the coal-face works is composed of reserve extraction labour costs, the costs related t the pneumatic energy used by the perforators and the coal-face hammers used in the work front, the costs related to the used electric power and the hydraulic aggregate which serves the coal-face as well as the transporters on the coal-face and its afferent flow of transport, the costs with prime matters and materials consumed in the production process, the costs with supporting and checking the equipment.

3.5.1 Costs with prime matters and materials used in the extraction process

The materials consumed during the production process and whose cost is found in the final cost of the extracted coal are:

• Mining wood used for supporting the coal-face junction with transport and airing pre-coal-faces for building the scarp;
• Metallic mesh used for building the flexible ceiling for the following slice;
• The anchoring string necessary for stitching the mesh rolls which make up the flexible ceiling as well as securing the support pillars to the GSA beams;
• Explosives and electric primers used in cutting the coal from the coal-face front.

3.5.2. Mining wood costs

The mining wood quantity used for extracting the reserve quartered in the coal-face field is calculated with due regard to the quantity of wood used both for the intermediary frames which are mounted on the two pre-coal-faces and the wood utilised for building the scarp that separates the exploited strata, using the following relation:

$$V_{lm} = V_{lmp} + V_{lms} = V_c \cdot n_c + V_{lms} = 0{,}398 \cdot l_{ca} \text{ [m}^3\text{]} \qquad (19)$$

where:
V_{imp} – the volume of wood utilised for the intermediary frames mounted in the pre-coal-faces;
V_{ims} – the volume of wood utilised for building the scarp;
V_c – the volume of wood utilised for building a frame;
$n_c = \frac{l_{ca}}{d}$, the number of (intermediary) support frames mounted on a pre-coal-face;
2 – represents the number of pre-coal-faces where support frames are being mounted;
l_{ca} – the length of the pre-coal-face, [m];
$d=0{,}8m$ – the distance between intermediary support frames;
$V_c = 0{,}123m^3$ – the volume of a support frame mounted on the pre-coal-face, [m^3/frame];

The relation for costs accrued with mining wood is as follows:

$$C_{lm} = V_{lm} \cdot k_{lm} = 0{,}398 \cdot l_{ca} \cdot k_{lm}, \text{ [lei]} \qquad (20)$$

where:
k_{lm} – represents the acquisition cost of a cubic meter of mining wood, [lei/m^3].

3.5.3. Modelling the metallic mesh costs

Metallic mesh is used in the coal extraction process especially for building the flexible ceiling for the following slice. In order to determine the amount of mesh that is used we must take account of the following:

- Mesh rolls are unrolled parallel to the work front and are secured between themselves with an anchoring string. These overlap on the previously mounted mesh rolls on a distance of 20 cm;
- The dimensions of a ballot: length = 5,5m; width = 1,35m; weight = 45kg, wire diameter = 4-4,2mm, Useful surface/ballot = 6,1 sqm, (useful length = 5,3m, useful width = 1,15m); specific mesh weight = 6 kg/m^2.

The total surface covered in metallic mesh is calculated using:

$$S_p = \frac{S_{rs}}{S_{us}} \cdot l_{ca} \cdot \left(l_{ab} + 2 \cdot l_{pr} \right) \text{[m}^2\text{]} \qquad (21)$$

where:

$\frac{S_{rs}}{S_{us}} = 1{,}21$ represents the fraction between real mesh roll surface and its useful surface. In order for the calculations to be rendered correct t is necessary that the covered surface is increased using this coefficient.

As such, the costs with metallic mesh relation will be:

$$\begin{aligned} C_{pm} &= \lfloor 1{,}21 \cdot l_{ca} \cdot (l_{ab} + 8) \rfloor \cdot \rho_{pm} \cdot k_{pm} \\ &= (7{,}33 \cdot l_{ca} \cdot l_{ab} + 58{,}66 \cdot l_{ca}) \cdot k_{pm} \end{aligned} \text{ [lei]} \quad (22)$$

where:

ρ_{pm} = 6,0 kg/m^2 metallic mesh specific weight;

k_{pm} – metallic mesh cost, [lei/kg].

3.5.4. Modelling explosives and electric primers costs

The amount of explosives used for extracting the coal from the coal-face field depends on a plethora of factors, the most important being the strength of the coal and the hole length that is being exploded. Generally, the amount of explosives used for an explosion is established through explosion disposition, occasion on which one establishes the maximum amount of explosive in the mining hole. In order to calculate the used amount of explosives the maximum quantity of 0,5kg/hole will be considered.

As such, the relation for calculating costs accrued with explosives is as follows:

$$C_{ex} = m_{ex} \cdot n_g \cdot n_c \cdot k_{ex} \text{ [lei]} \quad (23)$$

where:

n_g – represents the number of mine holes perforated for advancing the work front with 1,25m, [holes/cycle];

n_c – the number of coal-face cycle effected for exploiting the whole reserve contoured using the preparation works;

m_{ex} – the average quantity of explosives loaded in the mine hole, [kg/hole];

k_{ex} – acquisition cost for 1 kg of explosives, [lei/kg];

$$n_g = l_{ab} \cdot h_{ab} \cdot \xi = 1{,}48 \cdot l_{ab} \cdot h_{ab} \text{ ,[holes/cycle]} \quad (24)$$

where:

ξ = 1,48 represents the perforation density, meaning the number of holes drilled in a square meter of coal-face front;

$$n_c = \frac{l_{ca}}{w_c} \quad (25)$$

Substituting relations [23] and [24] in relation [22] we obtain the relation for the costs accrued with the explosives, which is as follows:

$$C_{ex} = 0{,}592 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot k_{ex} \text{ [lei]} \quad (26)$$

The costs with the electric primers used for initiating the explosive charges are calculated using:

$$C_{cp} = 1{,}184 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot k_{cp} \text{ [lei]} \quad (27)$$

where:

k_{cp} – represents the acquisition cost of a primer, [lei/each].

Summing relations [26] and [27] results in the relation for total costs effected with explosives and primers used in exploiting the whole coal-face field.

$$C_{tex} = l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot (0{,}592 \cdot k_{ex} + 0{,}184 \cdot k_{cp}) \text{[lei]} \quad (28)$$

3.5.5. Modelling costs with the anchoring string

The anchoring string is used for stitching the metallic mesh when building the artificial ceiling which helps separate the caved rocks from the slice under exploitation from the coal.

In order to execute the flooring, the ballots are continuously stitched together with the string (with double knots each 0,33m, 12cm string/knot), which are laterally overlapped and in the end on 0,2m – 9,6 ml string/ballot. Regarding everything mentioned the calculus relation for costs with the anchoring string is as follows:

$$C_s = 1{,}44 \cdot l_{ca} \cdot l_{ab} \cdot k_s \text{ [lei]} \quad (29)$$

where:

k_s – represents the acquisition cost of the anchoring string, [lei/lm].

The costs accrued with the materials used in the production process is as follows:

$$\begin{aligned} C_m &= C_{lm} + C_{pm} + C_{ex} + C_s = l_{ca}(0{,}398 \cdot k_{lm} + 58{,}66 \cdot k_{pm}) \\ &+ l_{ca} \cdot l_{ab}(7{,}33k_{pm} + 1{,}44 \cdot k_s) \\ &+ l_{ca} \cdot l_{ab} \cdot h_{ab}(0{,}592 \cdot k_{ex} + 0{,}184 \cdot k_{cp}) \end{aligned} \text{ [lei]} \quad (30)$$

3.6. Energy costs

3.6.1. Electricity costs

In order to determine this category of costs it is necessary to determine the maximum quantity of electricity used during the coal-face process, identifying exactly the consumers of electricity during the production process. As such:

- Bladed transporter type TR-3 or TR-5 mounted on the coal-face;
- Bladed transporters mounted on the transport pre-coal-face type TR-5;
- Bladed transporters type TR-5 mounted on the directional transport gallery;
- Hydraulic aggregate which allows for individual support on the coal-face.

The calculus relation for costs accrued with energy consumed during the extraction process is as follows [2], [4], [6]:

$$C_e = C_{e1} + C_{e2} \text{ [lei]} \quad (31)$$

where:

C_{e1} – represents the cost of the energy used by the transporters, [lei];

C_{e2} – represents the cost of the energy used by the hydraulic aggregate used in the coal-face, [lei];

In order to simplify the calculations and homogenise the interventions, the transporters mounted on the coal-face and the transport flow which serves the coal-face will be of the same type (TR-5).

As such, the costs accrued with energy spending for production transport will be calculated using:

$$C_{e1} = 1{,}6 \cdot l_{ca} \cdot l_{ab} \cdot \frac{h_{ab}}{\lambda_u} \cdot \frac{P_t}{Q_t}\left(1 + \frac{l_{ca}}{60} + \frac{l_p}{120}\right) \cdot k_e \text{ [lei]} \quad (32)$$

where:

P_t – the power of the transporters mounted on the coal-face, pre-coal-face nad the directional transport gallery up to the main flow, [kW];

λ_u =0,85 – represents the utilisation coefficient of the transport's equipment capacity;

Q_t - technical flow of the transporters, [t/h];

k_e – the price of a kWatt used during the production process, [lei/kWatt].

The costs with the energy used by the hydraulic aggregate which provides the working pressure for the SVJ pillars in the coal-face is to be calculated using the following:

$$C_{e2} = 3{,}2 \cdot l_{ca} \cdot \frac{(l_{ab} + 8)}{d_s} \cdot \frac{P_{ah}}{\lambda_s} \cdot t_0 \cdot k_e \text{ [lei]} \quad (33)$$

where:

P_{ah} - represents the power of the motor which engages the hydraulic aggregate, [kW];

λ_s = 1,2 – simultaneity coefficient (indicates the number of pillars tensioned simultaneously in the coal-face);

d_s = 0,8m – the distance between the support frames mounted in the coal-face, [m];

t_0 - the time it takes the hydraulic aggregate to bring a pillar under tension, [min/pillar];

By summing up relations [32] and [33] one obtains the final relation for costs accrued with used electric power, which is as follows:

$$C_{ee} = 1{,}6 \cdot l_{ca} \cdot k_e \left[\begin{array}{l} \dfrac{l_{ab} \cdot h_{ab}}{\lambda_u} \cdot \dfrac{P_t}{Q_t}\left(1 + \dfrac{l_{ca}}{60} + \dfrac{l_p}{60}\right) \\ +2 \cdot \dfrac{(l_{ab} + 8)}{d_s} \cdot \dfrac{P_{ah}}{\lambda_s} \cdot t_0 \end{array}\right] \text{[lei]} \quad (34)$$

3.6.2. Costs with pneumatic power

The calculus relation for such costs [2], [6], is as follows:

$$C_{ep} = C_{ep1} + C_{ep2} \text{ [lei]} \quad (35)$$

where:

C_{ep1} – costs accrued with pneumatic power during the perforation process, [lei];

C_{ep2} – Costs accrued with pneumatic power during the process of cutting the coal with the coal-face hammer, [lei].

The total length of the hole drilled for exploiting the reserve in the coal-face field is to be calculated using:

$$l_g = n_g \cdot l_g \cdot n_c = l_{ab} \cdot h_{ab} \cdot \xi \cdot \frac{w_c}{c_r} \cdot \frac{l_{ca}}{w_c} = 1{,}64 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot \frac{1}{\lambda_r} \text{ [m]} \quad (36)$$

where:

ξ = 1,48 represents the density of the drilled holes in a m^2 of coal-face field;

λ_r = 0,9 represents the holes' breaking coefficient.

$$C_{ep1} = l_g \cdot c_{s1} \cdot k_{ep} = 1{,}64 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot c_{s1} \cdot k_{ep} \text{ [lei]} \quad (37)$$

where:

c_{s1} = *8,53* m^3/ml represents the specific compressed air consumption of the utilised perforator;

k_{ep} – represents the cost of a m^3 of compressed air, [lei/m^3].

In order to calculate the costs accrued with pneumatic power used for the coal-face hammers we will consider the coal-face hammer would depilate a maximum of 10% of the total volume of coal from the front. Here we include all necessary operations in the front (breaking oversize, digging up pestles, cleaning the home, depilating coal in the ceiling).

$$C_{ep2} = 0{,}1 \cdot V_c = 0{,}1 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot c_{s2} \cdot k_{ep} \text{ [lei]} \quad (38)$$

where:

c_{s2} = 1,3 – represents the specific compressed air consumption of the coal-face hammer, [m^3air/m^3coal];

Summing up relations [37] and [38] we obtain the calculus relation for costs accrued with pneumatic power:

$$C_{ep} = l_{ca} \cdot l_{ab} \cdot h_{ab} \cdot k_{ep}(1{,}64 \cdot c_{s1} + 0{,}1 \cdot c_{s2}) \text{[lei]} \quad (39)$$

As such, the relation for costs effected with power used for extracting coal from the coal-face field is as follows:

$$C_e = l_{ca} l_{ab} h_{ab} \left[\begin{array}{l} \dfrac{1{,}6}{\lambda_u} \dfrac{P_t}{Q_t}\left(1 + \dfrac{l_{ca}}{60} + \dfrac{l_p}{60}\right) \cdot k_e \\ +(1{,}64 \cdot c_{s1} + 0{,}1 \cdot c_{s2}) \cdot k_{ep} \end{array}\right] \text{ [lei]} \quad (40)$$
$$+3{,}2 \cdot l_{ca} \frac{l_{ab} + 8}{d_s} \frac{P_{ah}}{\lambda_s} \cdot t_0 \cdot k_e$$

3.7. Modelling costs with wages

In order to model this group of costs it is necessary to know their and component elements' structure. The structure of these costs is as follows:

- Component elements: negotiated tariff salaries, bonuses (categorised), premiums, social security taxes, etc are important in shaping the costs which are regulated by way of normative acts and upon which there is no power of intervention;
- The personnel categories (workers, management staff) are very useful in determining the shifts that occur in the personnel structure for comparisons with in-force legislation as well as establishing precisely the value of the work provided in comparison with the basic requirements;
- Salary types which are used to characterise their efficiency.

Analysing the simple production process implies a qualitative analysis of the technological steps which make up the coal-face process. During this analysis the component phases of the coal-face process are exactly identified as well as their succession, restrictions imposed by the equipment and those imposed by health and safety regulations for the mining industry. Having an exact description of the geo-mining situation in the work front allows us to establish, based on working regulations, the quantity of work and number of people necessary for efficiently running the extraction process of the coal from the coal-face front under analysis.

The work consumption realised for advancing the coal-face front with an advancement step w_c was calculated considering the work volumes realised in the work front and work and time norms established in base [3].

The balance equation for work consumption per production cycle, during a simple process is as follows [10], [11]:

$$n \cdot t = M \qquad (41)$$

where:

n – the number of people necessary for realising the simple production process in a coal-face cycle;

t – the duration of a production shift, [unit of time];

M – the total work quantity necessary for realising a total production cycle.

The relation for determining the total quantity of work necessary for realising a total production cycle is as follows:

$$M = 84{,}15 \cdot l_{ab} \cdot h_{ab} + 74{,}93 \cdot l_{ab} + 104{,}26 \cdot h_{ab} + 1387{,}49 + 25 \cdot n \ \text{[min]} \qquad (42)$$

The total number of workers necessary for a total production cycle with an advancement of the coal-face front with a pace wc = 1,25m, is calculated using the following:

$$N_p^c = 0{,}2325 \cdot l_{ab} \cdot h_{ab} + 0{,}206 \cdot l_{ab} + 0{,}289 \cdot h_{ab} + 4{,}274 \ \text{[works/cycle]} \qquad (43)$$

The necessary number of workers for exploiting the reserve afferent to the functioning coal-face field is to be calculated using the following:

$$n_p^{ca} = N_p^c \cdot \frac{l_{ca}}{w_c} = 0{,}186 \cdot l_{ca} \cdot l_{ab} \cdot h_{ab} + 0{,}164 \cdot l_{ca} \cdot l_{ab} + 0{,}2312 \cdot l_{ca} \cdot h_{ab} + 3{,}419 \cdot l_{ca} \ \text{[works]} \qquad (44)$$

where:

$$n_c = \frac{l_{ca}}{w_c} \ \text{[cycles]} \qquad (45)$$

represents the number of cycles necessary for totally extracting the reserve afferent to the coal-face field under exploitation.

The salary costs effected for extracting the reserve during a production cycle are to be calculated using the following:

$$S_{ma} = S_{ma}^M + S_{ma}^A + S_{ma}^V, \text{[lei/cycle]} \qquad (46)$$

where:

$S^M{}_{ma}$ – the salary costs generated by paying the labour of a miner;

$S^A{}_{ma}$ – the salary costs generated by paying the labour of an assistant miner;

$S^V{}_{ma}$ – the salary costs generated by paying the labour of a hauler.

This relation has been calculated considering the provisions found in the *Notebook of unified work norms and regulations in the Jiu Valley Mining Basin* [13] which refer to organising work, the work formation and allocating workers on technological phases across the coal-face front. Utilising another work formation structure will inevitably lead to an increase in the share of salary costs in the final cost of the coal tonne extracted from the coal-face.

$$\begin{aligned} S_{ma} &= S_{ma}^M \left(0{,}116 \cdot l_{ab} \cdot h_{ab} + 0{,}151 \cdot l_{ab} + 0{,}144 \cdot h_{ab} + 2{,}502\right) \\ &+ S_{ma}^A \left(0{,}067 \cdot l_{ab} \cdot h_{ab} + 0{,}151 \cdot l_{ab} + 0{,}144 \cdot h_{ab} + 2{,}502\right) \\ &+ S_{ma}^V \left(0{,}138 \cdot l_{ab} \cdot h_{ab} + 0{,}009 \cdot l_{ab} + 0{,}128\right) \end{aligned} \ \text{[lei/cycle]} \qquad (47)$$

This type of costs varies according to a non-linear law being directly connected to the obtained production.

The total salary costs effected for extracting the reserve afferent to the coal-face field under exploitation are to be calculated using the following:

$$C_{ma} = n_c \cdot S_{ma} = \frac{l_{ca}}{w_c} \cdot S_{ma} = 0{,}8 \cdot l_{ca} \cdot S_{ma} \ \text{[lei]} \qquad (48)$$

3.8. Establishing the duration of a production cycle and the advancement speed of the coal-face front

Knowing the total number of workers necessary to realise a total production cycle we can determine its duration according to the number of shifts in a working day and the number of workers composing the work formation in a shift.

Having due regard to these factors the calculus relation for the duration of a production cycle will be as follows:

$$T_c = 0,0581 \cdot \frac{l_{ab} \cdot h_{ab}}{n_{sch}} + 0,0515 \frac{l_{ab}}{n_{sch}} + 0,0722 \frac{h_{ab}}{n_{sch}} + 1,068 \frac{1}{n_{sch}} \text{ [days]} \qquad (49)$$

where:

n_{sch} – represents the number of workers composing a work formation placed in the coal-face front during a shift;

The advancement speed of the work front is in direct relation to the duration of the production cycle, resulting the following relation:

$$v_z = \frac{w_c}{T_c} \text{ [m/day]} \qquad (50)$$

Replacing in the previous relation the value for the advancement step of the coal-face front and the duration of the cycle the speed advancement calculus relation becomes:

$$v_{ab} = \frac{w_c}{0,0581 \frac{l_{ab} h_{ab}}{n_{sch}} + 0,0515 \frac{l_{ab}}{n_{sch}} + 0,0722 \frac{h_{ab}}{n_{sch}} + \frac{1,06}{n_{sch}}} \text{ [m/day]} \qquad (51)$$

3.9. Elaborating the mathematical model for determining the dimensional parameters of the coal-face field

The mathematical model used to determine the coal-face field's dimensional parameters is based on the mathematical relations by way of which the costs effected with the production process have been calculated. By summing up these relations the total costs function has been established for extracting the reserve afferent to the coal-face field which is under exploitation.

By reporting the total costs realised for extracting the reserve afferent to the coal-face field under exploitation we get the unitary cost of the extracted coal tonne. This cost includes the costs effected up to the mail flow of transport.

The relation which determines the total exploitation costs is as follows:

$$\begin{aligned} C_t &= K_1 \cdot l_{ca}^2 + K_2 \cdot l_{ca}^2 \cdot l_{ab} + K_3 \cdot l_{ca}^2 \cdot h_{ab} \\ &+ K_4 \cdot l_{ca}^2 l_{ab} h_{ab} + K_5 \cdot l_{ca} + K_6 \cdot l_{ca} \cdot l_{ab} \\ &+ K_7 \cdot l_{ca} h_{ab} + K_8 \cdot l_{ca} l_{ab} h_{ab} + K_9 \cdot l_{ca} l_{ab}^2 \text{ [lei]} \\ &+ K_{10} \cdot l_{ca} l_{ab} h_{ab}^2 + K_{11} \cdot l_{ca} l_{ab}^2 h_{ab} \\ &+ K_{12} \cdot l_{ca} l_{ab}^2 h_{ab}^2 + K_{13} \cdot l_{ab} + K_{14} \cdot l_{ab} h_{ab} \end{aligned} \qquad (52)$$

In order to simplify the relation, the inserted coefficients have the following formulas:

$$K_1 = 3,44 \cdot 10^{-4} \cdot k_{gc} \cdot \frac{1}{n_{sch}} + 5,73 \cdot 10^{-5} \cdot \frac{V_{tpr}}{D_2} \cdot \frac{1}{n_{sch}} \qquad (52.a)$$

$$K_2 = 1,66 \cdot 10^{-5} \cdot k_{gc} \cdot \frac{1}{n_{sch}} + 2,76 \cdot 10^{-6} \cdot \frac{V_{tpr}}{D_2} \cdot \frac{1}{n_{sch}} \qquad (52.b)$$

$$K_3 = 1,94 \cdot 10^{-5} \cdot k_{gc} \cdot \frac{1}{n_{sch}} + 3,23 \cdot 10^{-6} \cdot \frac{V_{tpr}}{D_2} \cdot \frac{1}{n_{sch}} \qquad (52.c)$$

$$\begin{aligned} K_4 &= 1,86 \cdot 10^{-5} \cdot k_{gc} \cdot \frac{1}{n_{sch}} + 3,06 \cdot 10^{-6} \\ &\cdot \frac{V_{tpr}}{D_2} \cdot \frac{1}{n_{sch}} + 0,026 \cdot \frac{P_t}{Q_t} \cdot \frac{k_e}{\lambda_u} \end{aligned} \qquad (52.d)$$

$$\begin{aligned} K_5 &= 0,008 \cdot \frac{V_{co}}{d} \frac{1}{v_s} + 2 \cdot k_{gc} \\ &+ 3,44 \cdot 10^{-4} \left(\frac{V_{pr} n_{pr}}{D_1} + \frac{V_{pp} n_{pp}}{D_2} + \frac{V_{ca} n_{ca}}{D_2} \right) \frac{1}{n_{sch}} \\ &+ 3,44 \cdot 10^{-3} \left(\frac{V_{tab} n_{tab}}{D_2} + \frac{V_{tgd}}{D_2} \frac{l_p}{120} \right) \frac{1}{n_{sch}} \\ &+ 3,44 \cdot 10^{-3} \frac{V_{ah}}{D_3} \frac{1}{n_{sch}} + 25,6 \frac{1}{d_s} \frac{P_{ah}}{\lambda_s} t_0 \cdot k_e \\ &+ 2,001 \cdot S_{ma}^M + 2,001 \cdot S_{ma}^A + 0,102 \cdot S_{ma}^V \\ &+ 0,398 \cdot k_{lm} + 58,66 \cdot k_{pm} \end{aligned} \qquad (52.e)$$

$$\begin{aligned} K_6 &= 1,72 \cdot 10^{-4} \left(2 \cdot k_{gc} + k_{sa} \right) \frac{1}{n_{sch}} \\ &+ 1,66 \cdot 10^{-4} \left(\frac{V_{pr} n_{pr}}{D_1} + \frac{V_{pp} n_{pp}}{D_1} + \frac{V_{ca} n_{ca}}{D_1} \right) \frac{1}{n_{sch}} \\ &+ 1,66 \cdot 10^{-4} \left(\frac{V_{tab} n_{tab}}{D_2} + \frac{V_{tgd}}{D_2} \frac{l_p}{120} \right) \frac{1}{n_{sch}} \\ &+ 1,66 \cdot 10^{-4} \frac{V_{ah}}{D_3} \frac{1}{n_{sch}} + 3,44 \cdot 10^{-3} \frac{V_{us}}{D_3} \cdot \frac{1}{d_s} \frac{1}{n_{sch}} \\ &+ 0,12 \cdot S_{ma}^M + 0,12 \cdot S_{ma}^A + 0,007 \cdot S_{ma}^V \\ &+ 3,2 \frac{1}{d_s} \frac{P_{ah}}{\lambda_s} \cdot t_0 \cdot k_e + 7,33 \cdot k_{pm} + 1,44 \cdot k_s \end{aligned} \qquad (52.f)$$

$$K_7 = 0,008 \cdot \frac{V_{co}}{d}\frac{1}{v_s}\left(\frac{80}{l_p}+\frac{1}{m}\right)$$

$$+1,94\cdot 10^{-4}\left(\frac{V_{pr}n_{pr}}{D_1}+\frac{V_{pp}n_{pp}}{D_1}+\frac{V_{ca}n_{ca}}{D_1}\right)\frac{1}{n_{sch}}$$

$$+1,94\cdot 10^{-4}\frac{V_{ah}}{D_3}\frac{1}{n_{sch}} \qquad (52.g)$$

$$+1,94\cdot 10^{-4}\left(\frac{V_{tab}n_{tab}}{D_2}+\frac{V_{tgd}}{D_2}\cdot\frac{l_p}{120}\right)\frac{1}{n_{sch}}$$

$$+0,115\cdot S_{ma}^{M}+0,115k\cdot S_{ma}^{A}$$

$$K_8 = 9,74\cdot 10^{-6}\left(2\cdot k_{gc}+k_{sa}\right)\frac{1}{n_{sch}}$$

$$+1,72\cdot 10^{-4}\left(0,5\cdot k_{gc}+\frac{100}{l_p}k_{gs}+2\cdot k_{gs}\right)\frac{1}{m}\frac{1}{n_{sch}}$$

$$+\frac{1,6}{\lambda_u}\frac{P_t}{Q_t}\cdot\left(1+\frac{l_p}{120}\right)k_e$$

$$+1,86\cdot 10^{-4}\left(\frac{V_{pr}\cdot n_{pr}}{D_1}+\frac{V_{pp}\cdot n_{pp}}{D_1}+\frac{V_{ca}\cdot n_{ca}}{D_1}\right)\frac{1}{n_{sch}}$$

$$+1,86\cdot 10^{-4}\left(\frac{V_{tab}n_{tab}}{D_2}+\frac{V_{tgd}}{D_2}\frac{l_p}{120}\right)\frac{1}{n_{sch}}$$

$$+1,86\cdot 10^{-4}\frac{V_{ah}}{D_3}\frac{1}{n_{sch}}+1,94\cdot 10^{-4}\frac{V_{us}}{D_3}\frac{1}{d_s}\frac{1}{n_{sch}}$$

$$+0,592\cdot k_{ex}+0,184\cdot k_{cp}+\left(1,64\cdot c_{s1}+0,1\cdot c_{s2}\right)k_{ep}$$

$$+0,0928\cdot S_{ma}^{M}+0,053\cdot S_{ma}^{A}+0,11\cdot S_{ma}^{V} \qquad (52.h)$$

$$K_9 = 8,32\cdot 10^{-6}\left(2\cdot k_{gc}+k_{sa}\right)\frac{1}{n_{sch}}$$

$$+1,66\cdot 10^{-4}\frac{V_{us}}{D_3}\frac{1}{d_s}\frac{1}{n_{sch}} \qquad (52.i)$$

$$K_{10} = 9,74\cdot 10^{-6}\begin{pmatrix}0,5\cdot k_{gc}+\frac{100}{l_p}\cdot k_{gs}\\ +2\cdot k_{gs}\end{pmatrix}\frac{1}{m}\frac{1}{n_{sch}} \qquad (52.j)$$

$$K_{11} = 9,34\cdot 10^{-6}\left(2k_{gc}+k_{sa}\right)\frac{1}{n_{sch}}$$

$$+8,32\cdot 10^{-6}\left(0,5\cdot k_{gc}+\frac{100}{l_p}k_{gs}+2k_{gs}\right)\frac{1}{m}\cdot\frac{1}{n_{sch}} \qquad (52.k)$$

$$+1,86\cdot 10^{-4}\frac{V_{us}}{D_3}\frac{1}{d_s}\frac{1}{n_{sch}}$$

$$K_{12} = 9,34\cdot 10^{-6}\begin{pmatrix}0,5\cdot k_{gc}+\frac{60}{l_p}\cdot k_{gs}\\ +2\cdot k_{gs}\end{pmatrix}\frac{1}{m}\cdot\frac{1}{n_{sch}} \qquad (52.l)$$

$$K_{13} = 0,008\cdot\frac{V_{co}}{d}\cdot\frac{1}{v_s}+\left(2\cdot k_{gc}+k_{sa}\right) \qquad (52.m)$$

$$K_{14} = \left(0,5\cdot k_{gc}+\frac{60}{l_p}\cdot k_{gs}+2\cdot k_{gs}\right)\frac{1}{m} \qquad (52.n)$$

The unitary cost is to be determined using the following relation:

$$c_u = \frac{C_t}{R_i}\ \text{[lei/t]} \qquad (53)$$

$$c_u = 0,67\cdot\left|\begin{array}{l} l_{ca}\left(\frac{K_1}{l_{ab}\cdot h_{ab}}+\frac{K_2}{h_{ab}}+\frac{K_3}{l_{ab}}+K_4\right)\\ +\frac{K_5}{l_{ab}\cdot h_{ab}}+\frac{K_6}{h_{ab}}+\frac{K_7}{l_{ab}}+K_8\\ +l_{ab}\left(\frac{K_9}{h_{ab}}+K_{11}+K_{12}\cdot h_{ab}\right)\\ +K_{10}\cdot h_{ab}+\frac{K_{13}}{l_{ca}\cdot h_{ab}}+\frac{K_{14}}{l_{ca}}\end{array}\right|\ \text{[lei/t]} \qquad (54)$$

4. Analysing the mathematical model and establishing the optimal values of the dimensional parameters afferent to the coal-face field

In order to establish the optimal dimensions of the coal-face field one can utilise multiple methods depending on a number of criteria, as follows: the inclination of the coal strata, its thickness, the presence of mullock intercalations in the strata, the tectonics degree of the deposit, universally available support and cutting equipment which is accessible to the mining operator, the method of closing the exploited space, etc.

Having due regard to the aforementioned and the actual state of the mining operator which exploits the reserve in the Jiu Valley mining basin it is necessary to establish the dimensional parameters of the coal-face field in relation to cost, because they do not possess the financial resources to re-technologize the activity, basically having to function in extreme conditions.

Having due regard to the large number of variables in the general costs equation, this equation will be solved by way of a sensitivity analysis, the values inserted in the calculus being related to the available geo-mining data, the obtained results determining the optimal values for the functioning parameters of the coal-face.

As such, the entry values for the variables which comprise the mathematical model will be:

- *The length of the coal-face front* (l_{ab}): 60÷200 m with a calculus step of 10m;
- *The length of the coal-face field* (l_{ca}): 100÷800m with a calculus step of 10m, determined by the inclined extension in the geologic bloc;
- *The height of the coal-face* (h_{ab}): 2,5m or 3,15m, depending on the technical equipment in the coal-face front;
- *The number of workers in a shift* (N_{sch}) in the work front: 8÷20 workers/shift, with a calculus step of two workers.

As such, after building up the info programme and generating the results we can establish the optimal values of the length of the coal-face front and the coal-face field according to *''the unitary cost of the coal tonne extracted from the coal-face''*, a crucial criterion in choosing the exploitation method that is to be applied.

For a work formation with 8 workers/shift the minimal values of the unitary cost resulted from the calculations are as follows:

- c_{min}*=241,11 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 250 m;
- c_{min}*=247,42 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 250 m;
- c_{min}*=254,07 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 250 m;
- c_{min}*=260,90 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 250 m;
- c_{min}*=267,82 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 250 m;
- c_{min}*=274,81 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 250 m;
- c_{min}*=281,84 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 250 m;
- c_{min}*=288,90 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 300 m.

The absolute minimum of the unitary cost values is recorder with l_{ab}=60 m and l_{ca}=250 m, its value being *241,1 lei/tonne.* Doing the calculations working with this value we obtain the following:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *6,31 lei/tonne* representing 2,61%;
- for lab=100 m the unitary cost is 12,96 lei/tonne higher reported to the reference value, an increase of 5,37%;
- for lab=120 m the unitary cost increases with 19,79 lei/tonne compared to the reference value, an increase of 8,20%;
- for lab=140 m the rate at which the unitary cost increases compared to the reference value is 26,71 lei/tonne, representing 11,07%;
- for lab=160 m the value of the unitary cost is higher than the reference value with 33,70 lei/tonne, a percentage increase of 13,97%;
- for lab= 180 m the unitary cost is higher than the reference value with 40,73 lei/tonne representing an increase of 16,89%;
- for lab=200 m the unitary cost increases with 47,79 lei/tonne compared to the reference value, representing an increase of 19,82%.

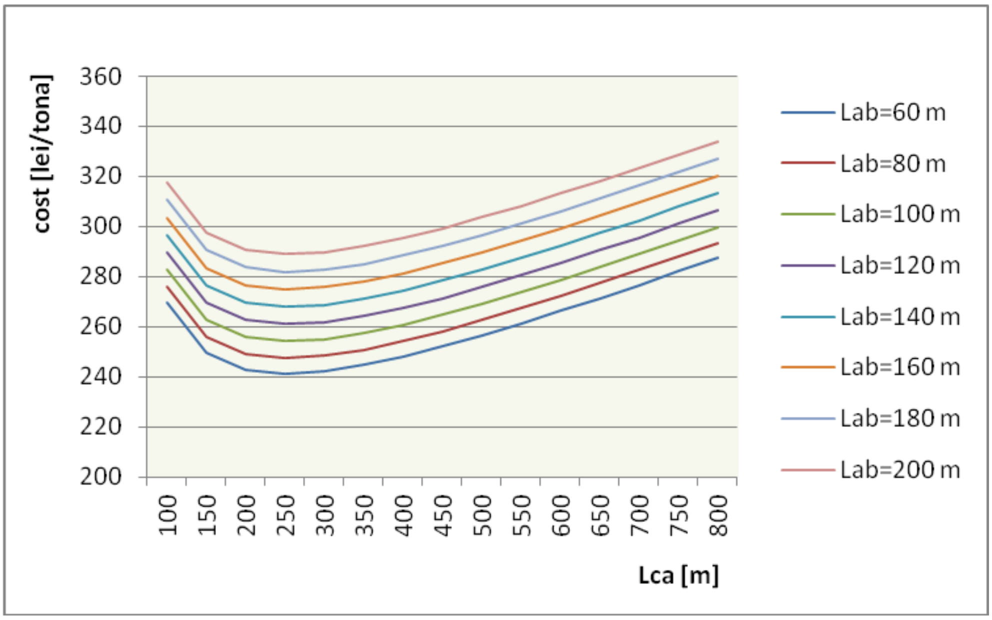

Fig. 2 *The variation graphic of the unitary cost $c_u=f(L_{ca})$ for frontal coal-faces with individual support, for N_{sch} = 8 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60 m ÷ 120 m and l_{ca}= 250 m***.

For a *work formation with 10 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*222,02 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 300 m;
- c_{min}=*226,23 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 300 m;
- c_{min}=*232,18 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 300 m;
- c_{min}=*237,59 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 300 m;
- c_{min}=*243,09 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 300 m;
- c_{min}=*248,65 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 300 m;
- c_{min}=*254,25 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 300 m;
- c_{min}=*259,88 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 300 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=300 m, it being *222,02 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *4,21 lei/tonne* representing 1,89%;
- for l_{ab}=100 m the unitary cost is *10,16 lei/tonne* higher reported to the reference value, an increase of 4,57%;
- for l_{ab}=120 m the unitary cost increases with *15,57 lei/tonne* compared to the reference value, an increase of 7,01%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *21,07 lei/tonne*, representing 9,49%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *26,63 lei/tonne*, a percentage increase of 11,99%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *32,23 lei/tonne* representing an increase of 14,51%;
- for l_{ab}=200 m the unitary cost increases with *37,85 lei/tonne* compared to the reference value, representing an increase of 17,05%.

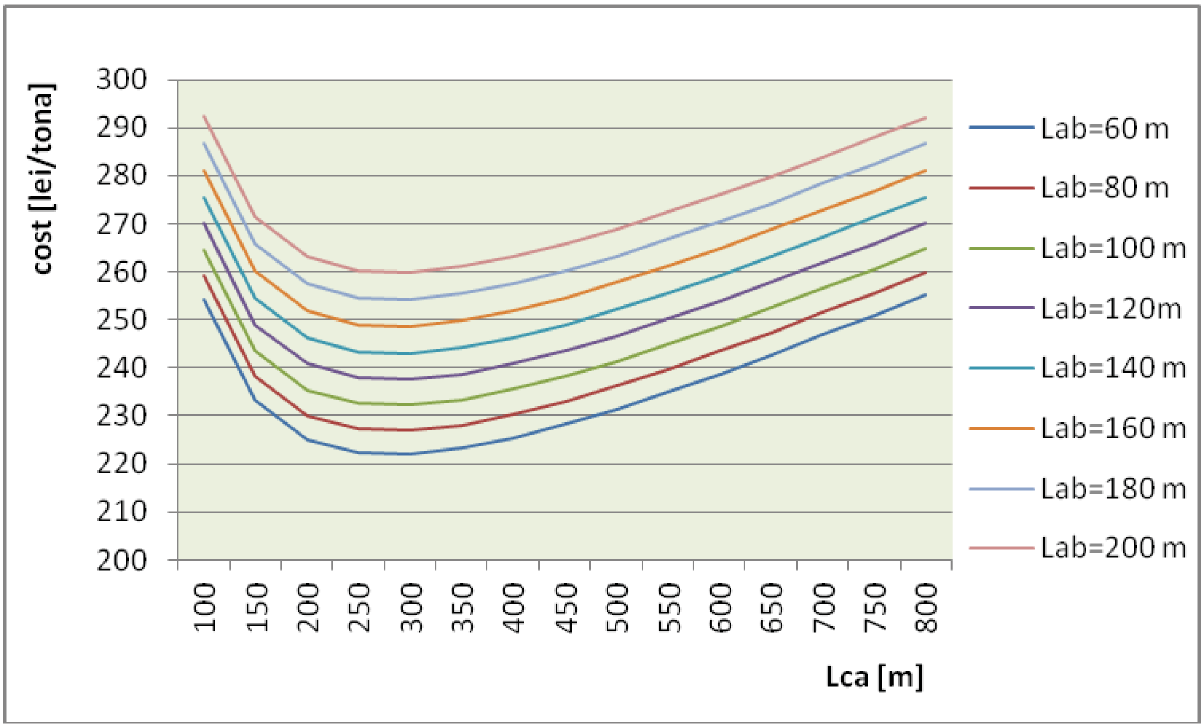

Fig. 3 *The variation graphic of the unitary cost $c_u=f(L_{ca})$ for frontal coal-faces with individual support, for N_{sch} = 10 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 140m și l_{ca}= 300 m***.

For a *work formation with 12 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*208,64 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 300 m;
- c_{min}=*212,65 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 300 m;
- c_{min}=*216,98 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 300 m;
- c_{min}=*221,45 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 300 m;
- c_{min}=*226,01 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 300 m;
- c_{min}=*230,99 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 300 m;
- c_{min}=*235,63 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 300 m;
- c_{min}=*239,97 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 300 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=300 m, it being *208,64 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *4,01 lei/tonne* representing 1,92%;
- for l_{ab}=100 m the unitary cost is *8,34 lei/tonne* higher reported to the reference value, an increase of 3,99%;
- for l_{ab}=120 m the unitary cost increases with *12,81 lei/tonne* compared to the reference value, an increase of 6,13%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *17,37 lei/tonne*, representing 8,32%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *22,35 lei/tonne*, a percentage increase of 10,71%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *26,99 lei/tonne* representing an increase of 12,93%;
- for l_{ab}=200 m the unitary cost increases with *31,33 lei/tonne* compared to the reference value, representing an increase of 15,01%.

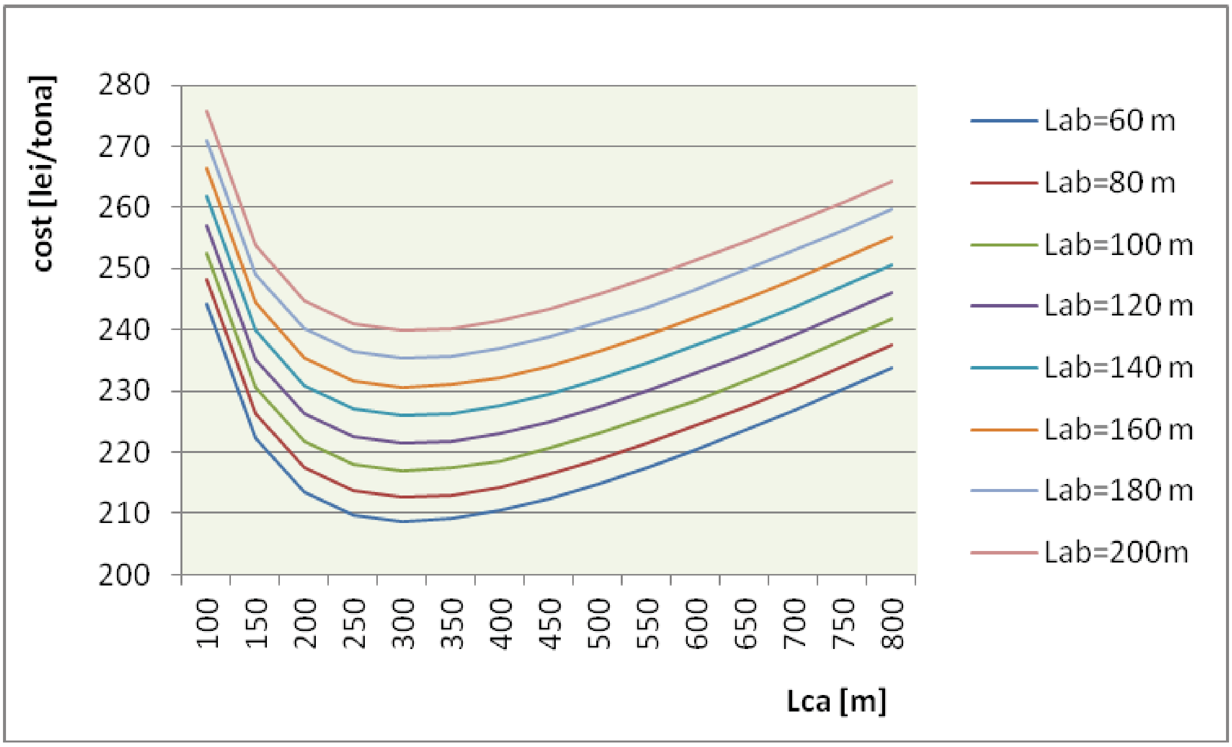

Fig. 4 *The variation graphic of the unitary cost c_u=f(L_{ca}) for frontal coal-faces with individual support, for N_{sch} = 12 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 140m și l_{ca}= 300 m***.

For a *work formation with 14 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*198,93 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 350 m;
- c_{min}=*202,28 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 350 m;
- c_{min}=*205,92 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 350 m;
- c_{min}=*209,72 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 350 m;
- c_{min}=*213,61 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 350 m;
- c_{min}=*217,54 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 350 m;
- c_{min}=*221,52 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 350 m;
- c_{min}=*225,52 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 350 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=350 m, it being *198,93 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *3,35 lei/tonne* representing 1,68%;
- for l_{ab}=100 m the unitary cost is *6,99 lei/tonne* higher reported to the reference value, an increase of 3,51%;
- for l_{ab}=120 m the unitary cost increases with *10,79 lei/tonne* compared to the reference value, an increase of 5,42%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *14,68 lei/tonne*, representing 7,37%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *18,61 lei/tonne*, a percentage increase of 9,35%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *22,59 lei/tonne* representing an increase of 11,35%;
- for l_{ab}=200 m the unitary cost increases with *26,59 lei/tonne* compared to the reference value, representing an increase of 13,36%.

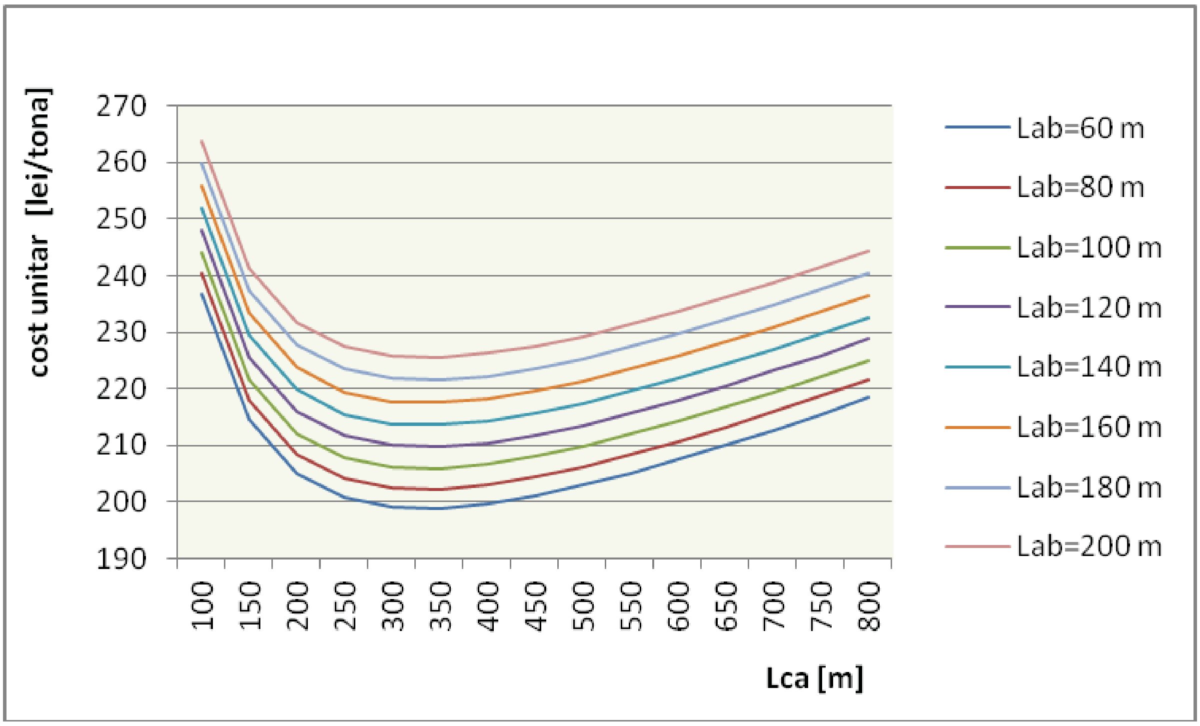

Fig. 5 *The variation graphic of the unitary cost $c_u=f(L_{ca})$ for frontal coal-faces with individual support, for N_{sch} = 14 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 160m și l_{ca}= 350 m***.

For a *work formation with 16 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*191,32 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 350 m;
- c_{min}=*194,19 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 350 m;
- c_{min}=*197,35 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 350 m;
- c_{min}=*200,65 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 350 m;
- c_{min}=*204,03 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 350 m;
- c_{min}=*207,46 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 350 m;
- c_{min}=*210,93 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 350 m;
- c_{min}=*214,82 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 350 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=350 m, it being *191,32 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *2,87 lei/tonne* representing 1,50%;
- for l_{ab}=100 m the unitary cost is *6,03 lei/tonne* higher reported to the reference value, an increase of 3,15%;
- for l_{ab}=120 m the unitary cost increases with *9,33 lei/tonne* compared to the reference value, an increase of 4,87%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *12,71 lei/tonne*, representing 6,64%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *16,14 lei/tonne*, a percentage increase of 8,43%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *19,61 lei/tonne* representing an increase of 10,24%;
- for l_{ab}=200 m the unitary cost increases with *23,50 lei/tonne* compared to the reference value, representing an increase of 12,28%.

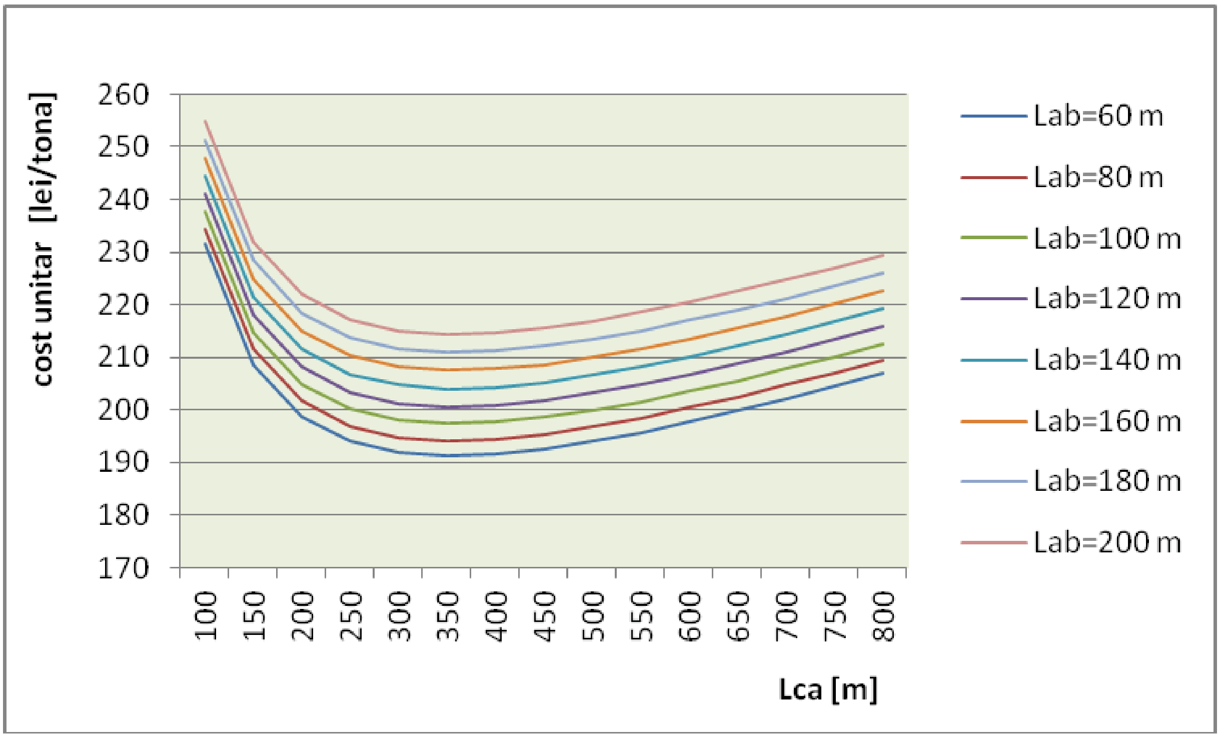

Fig. 6 *The variation graphic of the unitary cost $c_u=f(L_{ca})$ for frontal coal-faces with individual support, for N_{sch} = 16 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 160m și l_{ca}= 350 m***.

For a *work formation with 18 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*185,41 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 400 m;
- c_{min}=*187,88 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 400 m;
- c_{min}=*190,64 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 400 m;
- c_{min}=*193,55 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 400 m;
- c_{min}=*196,53 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 400 m;
- c_{min}=*199,57 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 400 m;
- c_{min}=*202,64 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 400 m;
- c_{min}=*205,73 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 350 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=400 m, it being *185,41 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *2,47 lei/tonne* representing 1,33%;
- for l_{ab}=100 m the unitary cost is *5,23 lei/tonne* higher reported to the reference value, an increase of 2,82%;
- for l_{ab}=120 m the unitary cost increases with *8,14 lei/tonne* compared to the reference value, an increase of 4,39%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *11,12 lei/tonne*, representing 5,99%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *14,16 lei/tonne*, a percentage increase of 7,63%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *17,23 lei/tonne* representing an increase of 9,29%;
- for l_{ab}=200 m the unitary cost increases with *20,32 lei/tonne* compared to the reference value, representing an increase of 10,95%.

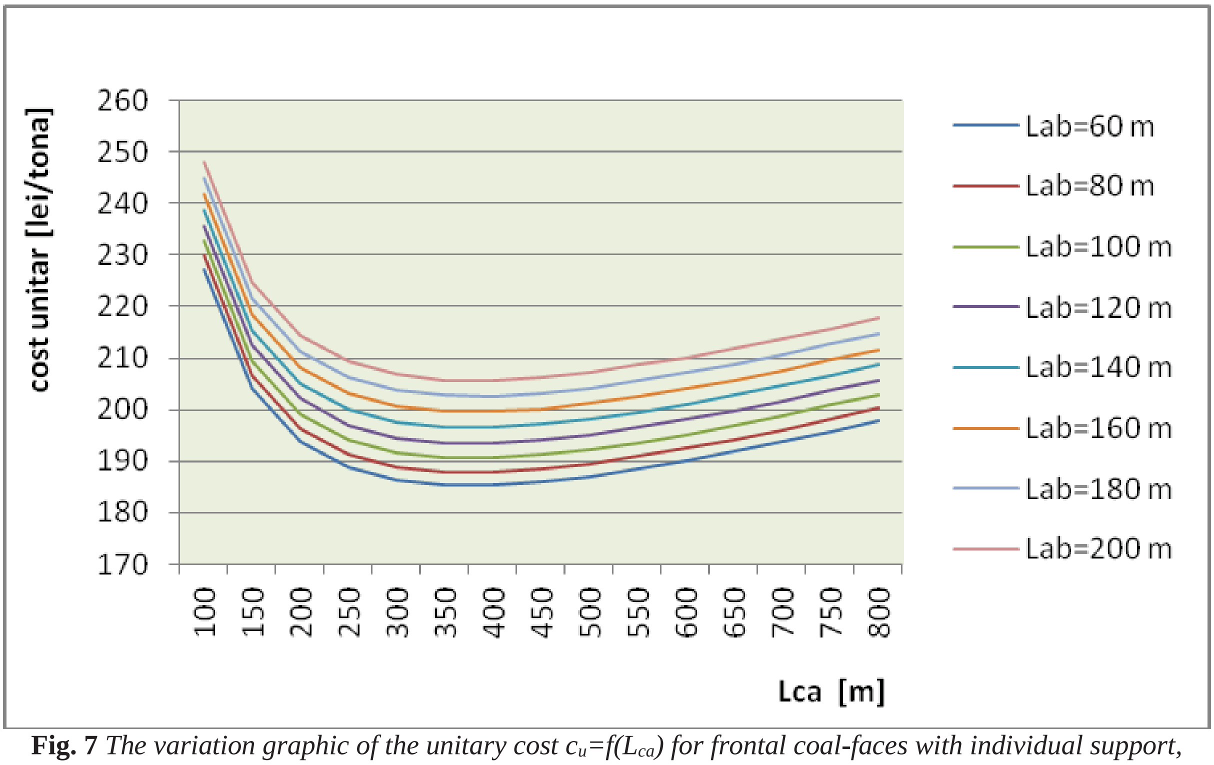

Fig. 7 *The variation graphic of the unitary cost c_u=f(L_{ca}) for frontal coal-faces with individual support, for N_{sch} = 18 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 180m și l_{ca}= 400 m***.

For a *work formation with 20 workers/shift* the minimal values of the unitary cost for each coal-face front length are:

- c_{min}=*180,40 lei/tonne*, for l_{ab}= 60 m and l_{ca} = 400 m;
- c_{min}=*182,58 lei/tonne*, for l_{ab}= 80 m and l_{ca} = 400 m;
- c_{min}=*185,04 lei/tonne*, for l_{ab}= 100 m and l_{ca} = 400 m;
- c_{min}=*187,63 lei/tonne*, for l_{ab}= 120 m and l_{ca} = 400 m;
- c_{min}=*190,31 lei/tonne*, for l_{ab}= 140 m and l_{ca} = 400 m;
- c_{min}=*193,03 lei/tonne*, for l_{ab}= 160 m and l_{ca} = 400 m;
- c_{min}=*195,78 lei/tonne*, for l_{ab}= 180 m and l_{ca} = 400 m;
- c_{min}=*198,56 lei/tonne*, for l_{ab}= 200 m and l_{ca} = 400 m.

The smallest value of the unitary cost is registered for l_{ab}=60 m and l_{ca}=400 m, it being *180,40 lei/tonne*. Using this value we reach the following conclusions:

- for l_{ab}=80 m the increase of the unitary cost compared to the reference value is *2,18 lei/tonne* representing 1,20%;
- for l_{ab}=100 m the unitary cost is *4,64 lei/tonne* higher reported to the reference value, an increase of 2,57%;
- for l_{ab}=120 m the unitary cost increases with *7,23 lei/tonne* compared to the reference value, an increase of 4,00%;
- for l_{ab}=140 m the rate at which the unitary cost increases compared to the reference value is *9,91 lei/tonne*, representing 5,49%;
- for l_{ab}=160 m the value of the unitary cost is higher than the reference value with *12,63 lei/tonne*, a percentage increase of 7,00%;
- for l_{ab}= 180 m the unitary cost is higher than the reference value with *15,38 lei/tonne* representing an increase of 8,52%;
- for l_{ab}=200 m the unitary cost increases with *18,16 lei/tonne* compared to the reference value, representing an increase of 10,06%.

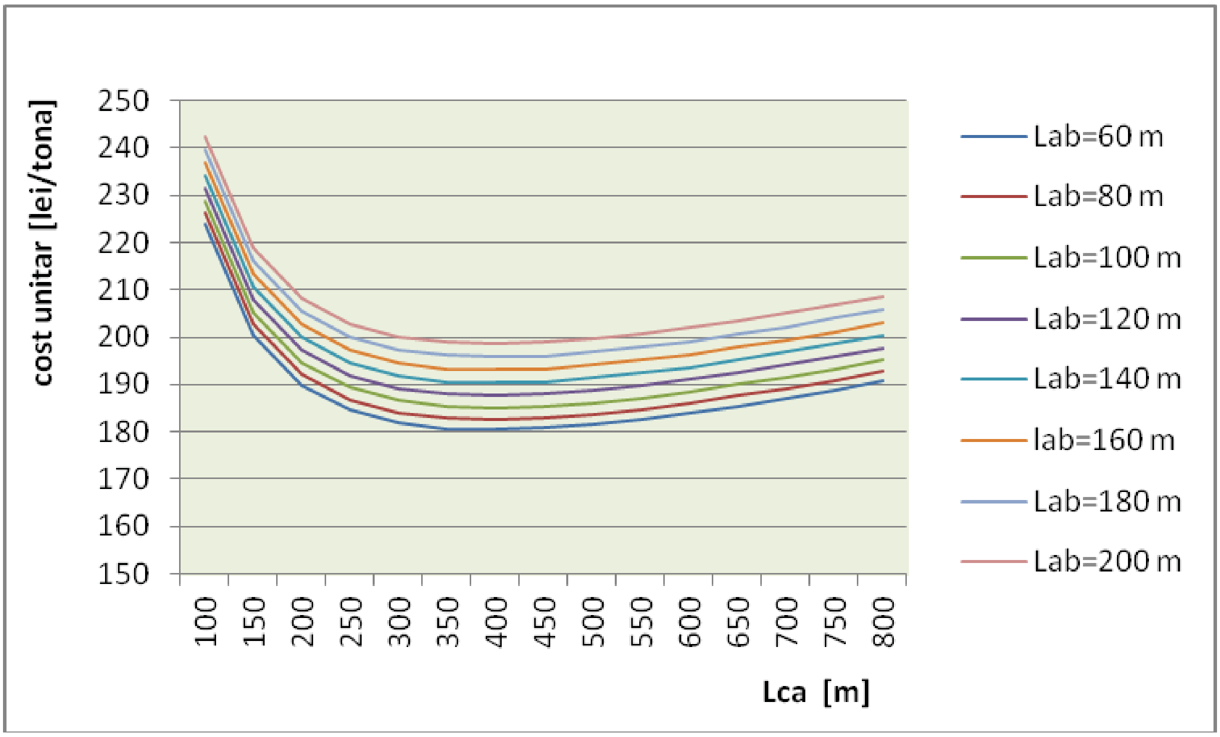

Fig. 8 *The variation graphic of the unitary cost $c_u=f(L_{ca})$ for frontal coal-faces with individual support, for N_{sch} = 20 workers/shift, h_{ab} = 3,15m and m= 20m*

Having due regard to the previously imposed framing restriction of ± 10% compared to the reference value we can establish as optimal values for the parameters of the coal-face field's under study, values which fall under the remit of the domain limits: ***l_{ab}= 60m ÷ 180m și l_{ca}= 400 m***.

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