EXECUTION OF BLASTING WORKS IN SALT MINES WITH METHANE ATMOSPHERE

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Abstract. The article presents the experiments carried out in a study performed in a salt mine with methane atmosphere, the results of which led to the identification of solutions for the execution of blasting works and the establishment of measures in order to carry out the activity of salt extraction in conditions of safety and efficiency. Experimental blasting works were done with the use of ordinary and permissible explosives taking into account the particularities of both the types of explosives used and those of the salt orebody. For this purpose, the parameters of the salt rocks (physical-mechanical and elastic-plastic characteristics, natural fragmentation of the rocks, etc.), the parameters of the mining works (the size of the mining section, the number of free surfaces of the front, etc.) were taken into analysis, blasting & drilling parameters (hole length, number of holes, distance between holes and rows of holes, amount of explosive per hole and total, etc.), as well as requirements imposed by the presence of methane gas in the mine air. After analyzing the results of the experimental blasting works, the drilling & blasting parameters and the most appropriate firing pattern that can be applied with the use of both ordinary and permissible explosives were established.

Keywords: salt mine, blast, methan gas, permissible explosive, drilling pattern

ВИКОНАННЯ ВИБУХОВИХ РОБІТ У СОЛЯНИХ ШАХТАХ З АТМОСФЕРОЮ МЕТАНУ

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Анотація. У статті представлені експерименти, проведені в дослідженні на фізіологічному розчині з сіруватим режимом, результати яких призвели до виявлення рішень для виконання вибухових робіт та встановлення заходів щодо здійснення діяльності з видобутку солі в умовах безпеки та ефективності. Експериментальні вибухові роботи проводились із застосуванням звичайних вибухових речовин та антигризозосних вибухових речовин з урахуванням особливостей як видів вибухових речовин, що використовуються, так і особливостей родовища солі. З цією метою аналізували параметри засолених порід (фізико-механічні та пружно-пластичні характеристики, природне дроблення гірських порід тощо), параметри гірничих робіт (розмір гірничої ділянки, кількість вільних поверхонь фронту тощо) були враховані для аналізу, параметрів вибухової роботи та буріння (довжина отвору, кількість отворів, відстань між отворами та рядами отворів, кількість вибухової речовини в отворі та загальна кількість тощо), а також вимоги наявність метанового газу в повітрі шахти. Після аналізу результатів експериментальних вибухових робіт, були встановлені буріння і вибухові параметри і найбільш підходящий шаблон випалу, який може бути застосований з використанням як звичайних, так і допустимих вибухових речовин.

Ключові слова: соляна шахта, вибух, газ метан, допустимі вибухові речовини, схема буріння.

1. Introduction

Considering the ensuring the state of security in the salt mines classified as having a methane regime, it was necessary to evaluate and establish the conditions for the execution of the blastting works, the use of explosives, as well as the way to achieve the quality control of the mine air. This was necessary considering the fact that the execution of the blastting works in the salt mines was done until now exclusively with ordinary explosives.

Thus, in a study conducted at a salt mine by specialists from the Department Security of Explosives and Pyrotechnic Articles of INSEMEX Petrosani, the aim was to establish the technical and safety requirements for the execution of blasting activities with the use of ordinary and permissible explosives.

For this purpose, the geological and technical-mining conditions specific to the salt orebody were analyzed, as well as the evidences, the existing documentation regarding the previous gas appearances, their manifestation and monitoring, experimentation and evaluation of the results of the blasting works with the use of different blasting patterns with ordinary and permissible explosives, respectively millisecond permissible electric detonators.

2. Methodology

2.1. Aspects regarding the classification of mines and underground mining works

The classification of mines and underground works is carried out taking into account the releases of explosive gases - methane as well as the releases of asphyxiating gases - carbon dioxide. Depending on the presence or absence of methane in the atmosphere of the mine / mine area, underground works or mass of rocks, they are classified as methane gassy or non-methane gassy.

The category of mines or underground works with methane gassy regime includes those mines, or underground works in which, following the measurements, the presence of methane in the underground atmosphere or in the rock massif was highlighted. Mines and underground works in which the presence of methane in the underground atmosphere was not found but in which in the test holes drilled in the rock body the presence of methane is found, it is considered as mines or underground works with methane gassy regime.

If the presence of methane has not been detected, in the secondary, main currents or with the ventilation stopped for 24 hours, the rock body is investigated by drilling 3 test holes with a length of at least 3 m , each, located on the surface of the mining front according to Figure 1. For the detection of methane, the wells for geological research performed in or towards the rock layer can also be used (Von Heinz, W.W.,1984):

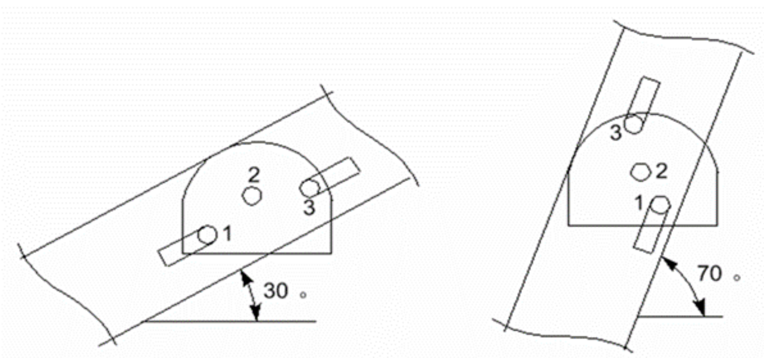

Figure 1 - Location of research holes

2.2. Classification of underground mining works of the salt mine

Following the quantitative and qualitative measurements performed in the main and secondary currents of ventilation air from the salt mine, in the active, inactive and in reserve mining works, the regime of gas emissions was established, respectively the classification category, depending on the absence or presence of methane and of carbon dioxide. In addition, specific measurements were made to determine the presence of methane gas during technological operations in the operating chambers, such as drilling blast holes, creating the cut at the base of the work fronts, at the chamber roof as well as in general airflow currents from the horizons and mine.

The results obtained from the measurements performed in the underground atmosphere and in the salt rock body, highlighted the following:

- the absence of methane during the development of technological processes such as drilling of test holes and baking of work fronts or after the execution of blasting works;

- the presence of methane in the salt body and in the marginal sterile rocks bodies as well as in the salt slots performed with the cutting machine and in the drilled mine holes.

Following the examination of the documentation and the elaboration of the Evaluation Report, INSEMEX Petroșani classified the underground mining works, from the point of view of gas emissions, as follows:

a) in the *"non-gassy regime",* the active, inactive and in reserve mining works, located under the depression created by the main ventilation station;

b) in category I of „ gassy *regime "*:

- ventilated workimg fronts with the help of partial ventilation installations in the closed end of mining galeries and chambers;
- fronts in which works are performed the following: cutting the slot with the cutting machine, drilling the blasting holes, executing the blasting works of the front, loading the blasted rock;
- the chambers in which well holes are drilled in order to investigate the salt deposit or the sterile intercalations and the salt / sterile contact area.

2.3. Considerations for performing underground blasting works

Achieving the desired blasting effects is conditional on setting the parameters of the blasting works so as to ensure the detachment of the rock from the massif, reducing over profiling and cracking area, obtaining an optimum granulometry and a reduced spread of the blasted rock mass (Lotze, S., 1993).

This presupposes that the drilling and blasting parameters are determined in correlation with the physical - mechanical characteristics of the rocks and the thermodynamics of the explosives used, respectively (Persson, P.A., Holmberg, et al, 1994):

- physical-mechanical and elastic properties, respectively natural fragmentation (on micro and macrocrystalline scale) of rocks;
- the section of mining works in the excavation and the depth at which they are located;
- number of free surfaces of the blasting front;
- drilling and blasting parameters;
- type of explosives and initiation means;
- type of explosive load;
- size and quality of stemming area.

When shaping the mined space in the salt mine, the self-bearing capacity of the massif must also be taken into account, respectively the protection of the cohesion of the massif must be taken into account in order to avoid the loss of resistance.As the connections between the salt rock particles are usually uniform, drilling and blasting works can be carried out schematically.This possibility of constantly blasting according to fixed patterns is an argument in favor of mechanizing drilling - blasting operations.In terms of perforability, the behavior of the salt mass allows holes of large length and diameter to be drilled, using rotary drilling, in a relatively short period of time.As a result, the performance of the drilling technique can be correlated with the requirements of the blasting technique.

2.4. Conditions for carrying out the blasting work in the salt mine

The method of salt exploitation is with small chambers and square pillars. Currently, salt is exploited at the last horizons - XI, XII and to a lesser extent at horizon X (Figure 2).

As the depth of operation increased, the dimensions of the chambers and pillars changed. If at the beginning of the operation, the chambers were 16 m wide and 8 m high, and the pillars had a side of 14 m, currently, on the horizons in operation, the chambers are between 12.0 - 13.5 m wide and 8 m high, and the pillars have a side of 16.5 m, leaving an 8 m thick floor between the horizons.

Today it is practiced to blast the front in one series, ascendingrow by row, starting from the bottom of chamber. Before drilling the front, a sloat with a depth of 3 m is cut at the level of the face bottom. The drilling of the front is performed with a Tamrock type installation equipped with an on-board computer that allows the setting of the drilling pattern, the installation then acting autonomously in terms of positioning and execution of holes.

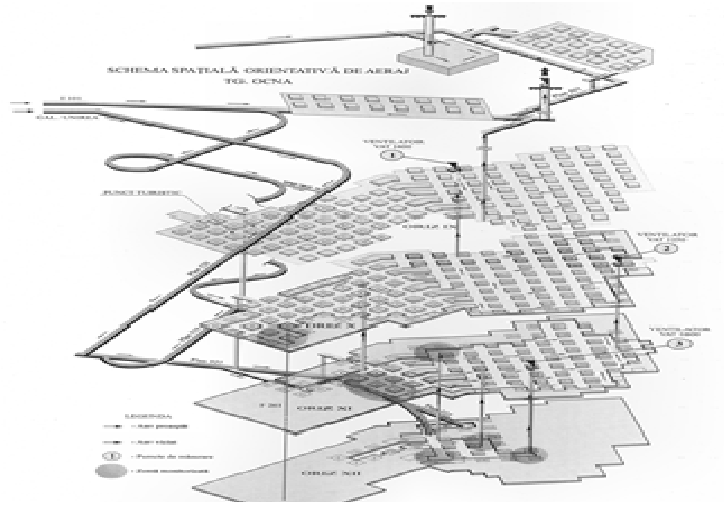

Figure 2 - Spatial scheme of exploitation of the salt mine

The firing patterns corresponding to this mode of operation and the drilling parameters have been established for the use of Astralita or Ammonite type explosives .The order of initiation is made by rows, starting from the bottom, the delay steps being made with intervals of one delay step. The holes from the contour of the chamber are initiated with the last delay step (Laszlo, R. et al, 2019).

***Technical specifications*:**

- ✓ Drilling parameters:
  - room with vaulted ceiling;
  - height in the shaft: h = 8 m;
  - width: l = 12 ÷13,5 m;
  - hole diameter: 40 mm;
  - hole length: max. 3 m;
  - hole spacing: 0,7 – 0,85 m up to max. 1,0 m;
  - row distance: 0,75 – 0,8 m up to max. 1,0 m;
  - no. of holes: max. 132;
  - no. of rows: max. 9;
  - stemming length: min.1/3 of hole length;
  - the creation of a second free surface by cutting at the bottom of the chamber with the help of a cutting machine, a slot on a depth of 3.0 m..
- ✓ Explosive materials used:
  - explosive used: Ammonex, Astralita;
  - initiation means: electric detonators type DEM-ZB-N (16 delays) and MMSED (18 delays), with a delay of 30 ms between two successive steps;
  - quantity of explosive/hole: max. 1,2 - 1,6 kg;
  - quantity of explosive used at a blast: max. 158 - 188 kg.;
  - millisecond blasting is practiced with detachment in rows from bottom to top.

Regarding the quantities of explosive possible to be detonated per delay depending on the seismic effect generated by the blasting works on underground mining structures, at intervals of three years INSEMEX Petroșani made seismic measurements in order to establish the explosive loads that they can be detonated instantly and or per delay (Laszlo, R. et al, 1992 – 1994).

Table 1 presents the maximum explosive charges allowed to be blast and which ensure the seismic protection of the inter room pillars and floors, established following the last seismic assessment performed in 2018.

Table 1

$Q_{max.inst.}$ [kg E TNT]	$Q_{max.per\ delay}$, [kg], depending on the duration of the blast (the total amount of delays ∑Δt, ms)															
	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480
71,0	47,0	45,2	42,6	38,6	33,6	30,8	28,4	26,6	25	23,8	22,6	21,8	20,8	20	19,4	18,8

- $Q_{max.inst.}$ - the maximum amount of explosive allowed to be blast instantaneously;
- $Q_{max.per\ delay}$ - the maximum amount allowed to be blast per delay (47,0÷18,8 kg) corresponding to the duration of the blast (30÷480 ms);
- ∑Δt is determined by considering the start of firing the first delay in the blasting circuit, regardless of its number, to which is added the value of the delay intervals between the following successive delay stages.

3. Results and discussions

3.1. Experimental blasts with the use of ordinary explosives

The performing of the experimental blasting works was made starting from the following premises:

- use as a reference the currently used framework blasting patterns and taking into account the main types and dimensions of mining works in the salt mine;
- when setting the blasting parameters (number of holes, distance between holes, distance between rows of holes, amount of explosive per hole), the quantities of explosive determined as the maximum allowed from a seismic point of view were also taken into account, to detonate instantaneously, and per delay;
- the creation of a second free surface, by cutting a slot at the bottom of the chamber, to a depth of 3,0 m;
- monitoring of methane gas emissions in front of the face, in mine holes, slot or test holes both at the end of the drilling process and before and after loading the holes with explosives;
- blasting a front in one round.

Ordinary explosives such as Ammonex 3, Riomax XE and Riomax HE were used for the blasting works. The parameters of these explosives are shown in Table 2. The initiation of the explosive charges was done with permissible electric millisecond detonators with a delay time between two consecutive steps of 30 ms.(Laszlo, R. et al, 2019).

Table 2

Explosive parameters	M.U.	Explosive type		
		Riomax HE	Riomax XE	Amonex 3
0.	1.	2.	3.	4.
I. Thermodynamic parameters:				
• oxygen balance;	%	-	-	0,26
• explosion heat;	KJ/KG	-	-	4040
• explosion temperature;	°K	473,15	473,15	2707
• volume of explosive gases;	L/kg	-	-	993
• volume of toxic gases CO;	L/kg	36,67	80,9	<4
• volume of toxic gases NO_2.	L/kg	31,97	992	<0,21
II. Physico – chemical parameters :				
• appearencet/ color;		hidrogel / gray	hidrogel / gray	Paste / white
• density, minim;	kg/dm^3	1,15	1,15	1,10
• humidity, maxim;	%	5,5	5,5	≤1,0
• stabilitity at 75°C , minim	minutes	15	15	15
III. Ballistic parameters:				
• detonation;	m/s	≥ 2800	≥ 2800	≥ 3600
• transmission of detonation	cm	≥ 2	≥ 2	≥ 5
• work capacity (Trauzl test);	cm^3	316	318	≥ 340
• brisance (Hess test);	mm	> 16	> 16	≥ 14
• equivalence coeffcient in TNT.		1,0	1,0	1,0
IV. Safety parameters:				
• sensitivity to shock;	J	≥ 50	≥ 50	≥ 50
• sensitivity to friction;	N	> 360	> 360	> 360
• maximum operating temperature;	°C	60±5	60±5	-20 ÷ +35
• freezing temperature;	°C	nu îngheaţă	nu îngheaţă	-25
V. Other parameters :				
• diameter;	mm	32	32	32
• cartridge length;	mm	200	200	220
• cartridge weigth	g	190	190	200
• shelflife	month	12	12	12

In a first stage, blasting works were performed using the Ammonex 3 type explosive and using the current blasting patterns applied in the salt mine This is shown in Figure 3 where with "L" was denoted the width of the chamber and with "d" the distance between the holes.

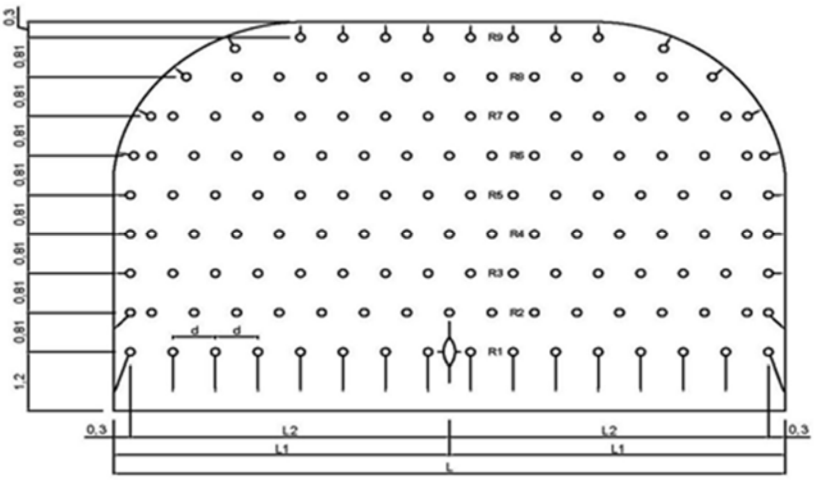

Figure 3 – Drilling pattern applied at level X, XI și XII – explosive Ammonex 3

The parameters with reference to the results of the blasting works which were monitored - breaking efficiency (jump), profiling of the mining face at walls and roof, granulometry of the blasted rock, distance of throwing of the blasted rock, disposition / geometry of the blasted rock from the front face, presence and the length of the remaining at the bottom of the blasted holes, the granulometry of the blasted rock and the distribution by granulometric classes (Laszlo, R. et al, 1988 – 1989).

The blasting works performed with the use of the Ammonex 3 explosive had the following drilling - blasting parameters:

- hole diameter: 40 mm;
- hole length: max. 3 m;
- hole spacing: 0,7 – 0,85 m;
- row distance: 0,75 – 0,8 m;
- distance from the bottom slot to the first row; 1,2 m;
- no. of holes: 132;
- no. of rows: 9;
- explosive type - Ammonex 3: length - 220 mm, diameter - 32 mm, weight - 200 gr.;
- electric detonators: 30 ms;
- quantity of explosive /hole: 5 – 7 cartridges / 1,2 - 1,6 kg;
- quantity of explosive per blast: max. 158 - 188 kg.
- initiation row by row starting from the bottom of the face.

The results of the blasting works were closely correlated with the characteristics of the salt in the fronts (white salt, gray-gray salt) and with the function of the arrangement of the fault plans in the massif. The results of the performed works were characterized by the following parameters (see Figure 4):

- breaking efficiency (jump): 2,7 – 2,9 m;
- profiling of mining construction on walls and roof: good;
- granulometry of the blasted rock: 60 – 70 % in the range of 0 - 200 mm;
  25 – 35 % in the range of 200 - 400 mm;
  5 – 10 % in the range of 400 - 600 mm.
- throwing distance of the blasted rock: 6 – 8 – 10 m;
- height of disposal of the blasted rock from the front face: 3 – 5 m;
- length of the remaining at the bottom of blasted rocks: 0,1 – 0,3 m.

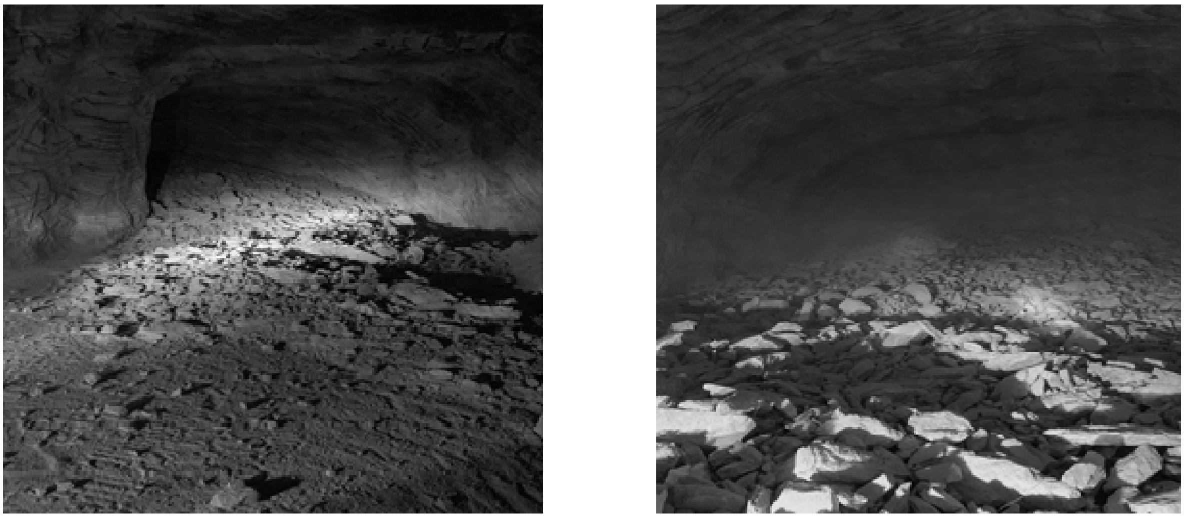

Figure 4 - Blast results with Ammonex 3 explosive type

Considering that in most of the blasting works, the jump was 2.7 - 2.9 m and in order to increase the blasting efficiency, an alternative pattern with drilled holes at a length of 2.5 m was also tested, the rest of the parameters remaining unchanged:

- hole diameter: 40 mm;
- hole length: 2,5 m;
- hole spacing: 0,76 m;
- row distance: 0,81 m;
- distance from the bottom slot to the first row; 1,2 m;
- no. of holes: 132;
- no. of rows: 9;
- explosive type - Ammonex 3: length - 220 mm, diameter - 32 mm, weight - 200 gr.;
- electric detonators: 30 ms;
- quantity of explosive /hole: 6 – 7 cartridges / 1,2 - 1,4 kg;
- quantity of explosive per blast: max. 160 kg.
- initiation row by row starting from the bottom of the face.

The results obtained in this variant of drilling – blasting pattern were better than in the other experimental works. Thus, the following parameters were obtained:

- breaking efficiency (jump): 2,4 m;
- profiling of mining construction on walls and roof: good;
- granulometry of the blasted rock: 75 - 85 % in the range of 0 - 150 mm;
10 - 20 % in the range of 150 - 250 mm;
5 - 10 % in the range of 250 - 350 mm.
- throwing distance of the blasted rock: 18 – 20 m;
- height of disposal of the blasted rock from the front face: 2 - 4 m;
- length of the remaining at the bottom of blasted rocks: 0,1 – 0,15 m.

Although this variant was satisfactory in terms of results, its experimentation was not continued in other configurations as it was not possible to correlate the length of the slot (salt mine have only cutting machine with an arm length of 3 m) with the length of the mine holes - 2,5 m. Following the blasting operation of the front, there was a tendency to remain at the bottom on the front wall, towards the slot, an area with a higher level that could affect the loading / evacuation of the blasted rock. This variant will be able to remain a viable option to be applied in the conditions in which it will be possible to cut the slot at the face bottom to lengths of 2.5 m.

In a second stage, blasting works were also carried out with the use of Riomax XE and Riomax HE explosives. The monitoring of the blasting parameters followed the same performance elements as in the case of experiments with the use of the explosive Ammonex 3.

At this stage, compared to the previous period of experimentation, in addition to the drilling - blasting patterns currently used in the salt mine, the following variants were used (Laszlo, R. et al, 1996 – 1998:

- the use of different explosive charges per hole, under the conditions of using the same drilling pattern (Figure 3) as follows: 1.25 - 1.5 - 1.75 kg / hole (5-8 explosive cartridges) on the first row of holes and 1.25 - 1.5 kg / hole (6 - 7 explosive cartridges) on the rest of the rows of holes;
- the variant with increasing the number of rows of holes, from 9 to 10 rows, by introducing an additional row from the bottom side and redistributing the distance between the holes and the rows of holes so that the distance from first row - R1 to the slot area becomes 0.8 m and the distance between the rest of rows R2 - R10 becomes 0.75 m. The number of holes increases from 132 to 148 pcs. (Figure 5);
- the variant with the supplementation of each row of holes with one hole, by redistributing the distance between the holes from 0.76 to 0.71 m; from 0.79 to 0.75 m; from 0.82 to 0.78 m and from 0.86 to 0.81 m., correlated with the width of the chamber.The number of holes increases from 132 to 141 pcs. (Figure 6).

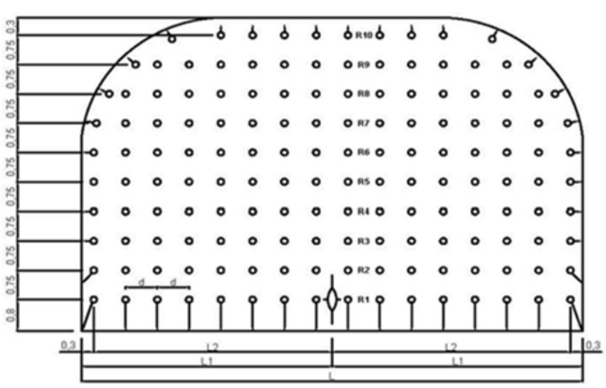

Figure-5 Pattern with an additional row of holes

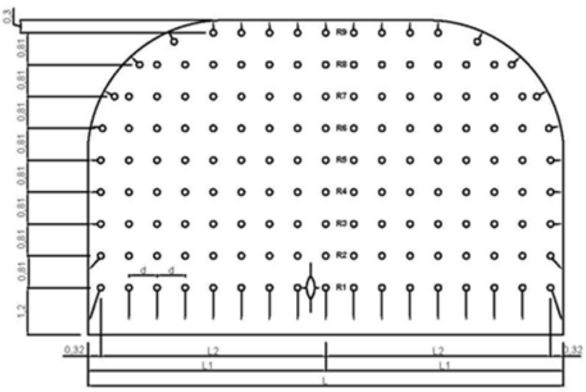

Figure- 6 Pattern with an additional hole per rows

The results of the blasting work confirmed the peculiarities of the results by blasting in salt rock encountered during the first stage. Thus, the results of the performed works were characterized by the following parameters (see Figure 7):

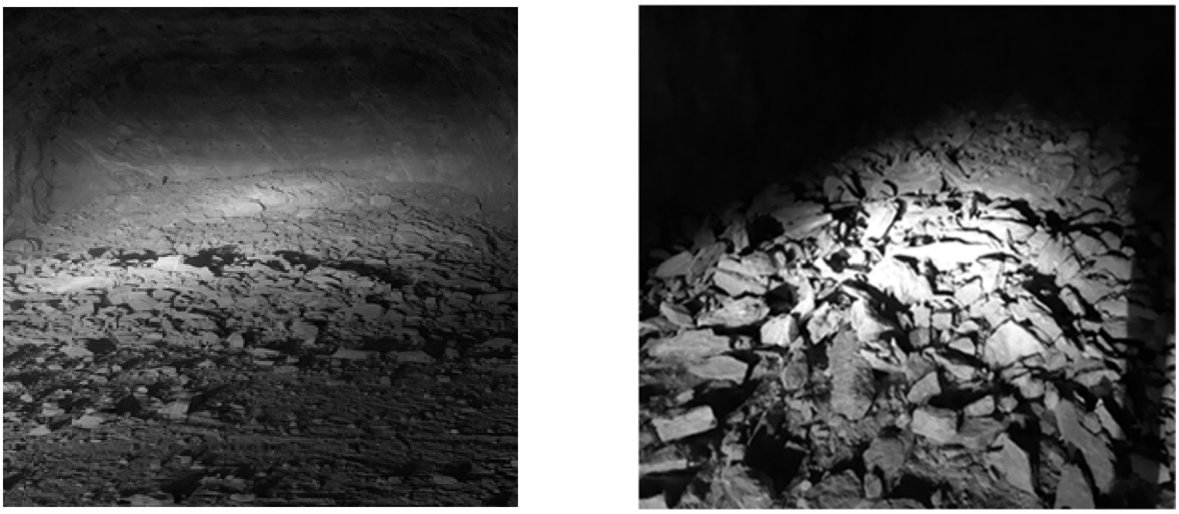

Figure 7. Blast results with Riomax XE and Riomax HE explosive types

- breaking efficiency (jump): 2,7 – 2,9 m;
- profiling of mining construction on walls and roof: good – very good;
- granulometry of the blasted rock: 70 – 80 % in the range of 0 - 300 mm;
  15 – 25 % in the range of 300 - 400 mm;
  5 – 10 % in the range of 400 - 600 mm.
- throwing distance of the blasted rock: 14 – 16 - 18 m;

- height of disposal of the blasted rock from the front face: 3 – 5 m;
- length of the remaining at the bottom of blasted rocks: 0,1 – 0,3 m.

3.2. Experimental blasting works with the use of permissible explosives

Emulinit PM and Rioper G permissible explosives were used in the blasting works. The parameters of these explosives are shown in Table 3.

Table 3

Explosive parameters	M.U.	Explosive type	
		Emulinit PM	Rioper G
0.	1.	2.	3.
I Physico – chemical parameters :			
• appearencet/ color;		Emulsion / white	Emulsion / white
• density, minim;	g/cm^3	1,15 – 1,21	1,49
• humidity, maxim;	%	5,5	1,3
• stabilitity at 75°C , minim	minutes	15	30
II. Ballistic parameters:			
• detonation;	m/s	>3600	≥1900
• transmission of detonation		≥2	1
• work capacity (Trauzl test);	cm^3	178	218
• brisance (Hess test);	mm	-	-
• equivalence coeffcient in TNT		1,0	1,0
III. Safety parameters:			
• sensitivity to shock;	J	≥50	3
• sensitivity to friction;	N	>360	>247
• maximum operating temperature;	°C	-10 ÷ +50	-10 ÷ +50
• storage temperature;	°C	+10 ÷ 30	+10 ÷ 30
IV. Other parameters :			
• diameter;	mm	32	32
• cartridge length;	mm	300	200
• cartridge weigth	g	300	250
• shelflife	month	6	6

In a first stage, blasting works were performed using the Emulinit PM type explosive and the current blasting patterns applied in the salt mine (Figure 3).

Compared to the blasting operations for which ordinary explosives were used, the results obtained when using the permissible explosive were less satisfactory. This can also be explained if we compare the ballistic parameters of these explosives presented in Tables 2 and 3.

However, it should be emphasized that the main quality of permissible explosives is their methane safety character, respectively increased security at the risk of igniting atmospheres with air-methane mixtures, being less efficient in terms of ballistic parameters. To all these aspects can be added the inhibitory character of the salt, which in turn contributes to the cooling of the explosion temperature, respectively to the reduction of the explosives performances.

The results of the experimental works performed were characterized by the following parameters (see Figure 8):

- breaking efficiency (jump): 2,6 – 2,8 m;
- profiling of mining construction on walls and roof: satisfactorily - good;
- granulometry of the blasted rock: 50 – 70 % in the range of 0 - 500 mm;
  20 – 30 % in the range of 500 - 700 mm;
  5 – 10 % in the range of 700 - 900 mm.
- throwing distance of the blasted rock: 12 – 16 – 18 m;
- height of disposal of the blasted rock from the front face: 4 – 6 m;
- length of the remaining at the bottom of blasted rocks: 0,2 – 0,4 m.

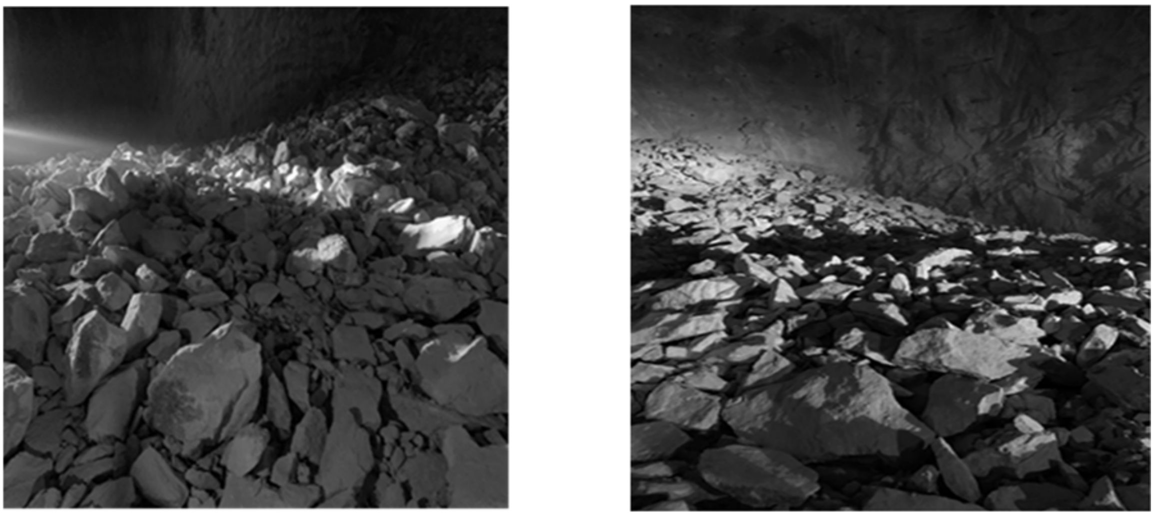

Figure 8 – Blast results with Emulinit PM permissible explosive type

In the second stage, blasting works were performed using the Rioper G - permissible explosive type. Compared to the previous experimentation period, in addition to the blasting pattern currently used in the salt mine (Figure 3), the following drilling & blasting variants were also used (Laszlo, R. et al,1999 – 2000):

- a drilling pattern was used with a staggered placement of the rows of holes (Figure 9);
- when using the current drilling – blasting pattern currently applied in the salt mine, the order of the delay steps was changed. The delay order was kept ascending, starting from the face bottom, but the delay interval between row no. 3 and row no. 4 was increased by three steps of delay, respectively by 90 ms (Figure 10).

This variant was intended to blast the front as if it were executed in two separate rounds. When the front is blasted, by the delay difference between the rows from the face bottom area and the rest of the rows, the rock from the perimeter of the first three rows is allowed to move outside the front face, thus creating a second free surface (much larger than that of the cutted slot). This allows a better functioning of the holes in the upper rows and which leads to an increase in the degree of the rock breakage, a reduction in the throwing distance as well as a better processing of the chamber profile.

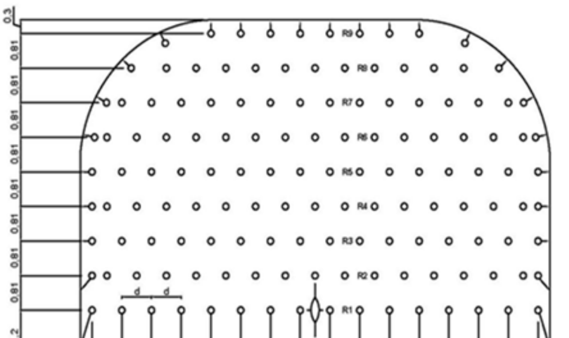

Figure 9 – Drilling & blasting pattern with staggered holes

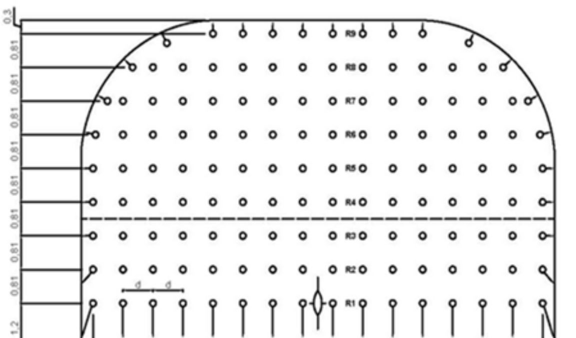

Figure 10 – Drilling & blasting pattern with 75 ms delay between row R_3 and R_4

The results of the blasting works highlighted the blasting pattern using the 90 ms delay gaps between row no. 3 and row no. 4. This variant was also tested with the use of the Riomax XE explosive, the results being also satisfactory. Regarding the variant of blasts with staggered holes, the obtained results did not give improved results and as a result it was abandoned.

The following results were obtained in the blasting works for which the pattern with delay times row by rows was modified compared to the currently applied one (see Figure 10 for Rioper G and Figure 11 for Riomax XE):

- breaking efficiency (jump): 2,7 – 2,9 m;
- profiling of mining construction on walls and roof: good;
- granulometry of the blasted rock: 40 – 50 % in the range of 0 - 300 mm;
  25 – 35 % in the range of 300 - 400 mm;
  5 – 15 % in the range of 400 - 600 mm.
- throwing distance of the blasted rock: 12 – 16 – 18 m;
- height of disposal of the blasted rock from the front face: 3 – 6 m;
- length of the remaining at the bottom of blasted rocks: 0,2 – 0,3 m.

Figure 10 – Blast results with Rioper G permissible explosive type

Figure 11 – Blast results with Riomax XE ordinary explosive type

4. Conclusions

The experiments presented in this article have led to the identification of solutions for carrying out the blasting work and the establishment of measures to allow the development of salt extraction in a safe and efficient manner. The experimental blasting works were done with the use of ordinary explosives and permissible explosives considering the particularities of both the types of explosives used and those of the salt ore body.

For this purpose, the parameters of the salt rocks (physical-mechanical and elasto-plastic characteristics, natural fragmentation of the rocks, etc.), the parameters of the mining constructions (the size of the mining section, the number of free surfaces of the front, etc.) were taken into analysis, drilling & blasting parameters (hole length, number of holes, holes spacing, rows distance, amount of explosive per hole and total, etc.), as well as the requirements imposed by the presence of methane gas in the mine air.

Following the analysis of the results of the experimental blasting works, it turned out that the most appropriate blasting pattern is the one in Figure 10. This blasting pattern can be applied to the use of both ordinary and permissible explosives.

At the location of the detonators delay stages, care must always be taken to ensure the creation of an additional free surface by using a time difference - three delay stages (75 - 90 milliseconds), between the third row of holes from the bottom of the face and the rest of the rows of holes.

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