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EXPLOITATION BELOW +193M ELEVATION OF THE ROCK SALT DEPOSIT FROM SLĂNIC PRAHOVA SALINE

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Abstract: *The rock salt deposit from Slănic Prahova was exploited starting in the 17th century up to +193m elevation, through the Old Mines, the Victoria Mine and the Cantacuzino Mine. In order to continue the mining activity at a production capacity of over 200 thousand tonnes per year, mining began under a 40 m-thick crown pillar, through horizons XIV and XV. The mining method used is with small rooms and square pillars, and the mining technology is by mechanized cutting with roadheader. The stability analysis of underground excavations and resistance structures (pillars and ceilings) was carried out by numerical modeling using the finite element method.*
Keywords: *rock salt, underground mining, rooms and pillars, ceiling, roadheader, drilling-blasting, numerical modeling, finite element, stability, stress, strength*

1. Geological and geomechanical characteristics of the Slănic-Prahova rock salt deposit

1.1. Geological characteristics

The beginning of the geological research of the Slănic Prahova rock salt deposit dates back to 1870, the year in which Fr., Sterle and Fr., Hauer published the first information on the Slănic region in Vienna. In 1887 Eng. G., Galeriu presented a study about the rock salt from Slănic in the work „On the saline grounds of Romania” [1], [2], [3], [4], [5].

In 1911 and 1912, the first more detailed studies by L., Mrazec, I.P., Voiteşti and V., Merentin appeared, and from 1937, geological research was intensified through exploratory drilling. The most complex synthesis report was made in 1967, later supplemented with other geological and hydrogeological documentation [1], [2], [3], [4], [5].

The rock salt deposit from Slănic Prahova has a lenticular shape, with a length of approx. 2,700 m, in the north-south direction, the width of the lens is between 800 and 2,300 m, and the maximum thickness is 499 m.

The genesis of the rock salt deposit from Slănic Prahova indicates the existence of a gulf formed, probably, during the regression of the flysch sea where, in the conditions of a very dry climate, the salts successively precipitated from the supersaturated waters.

At Slănic and respectively in the area crossed by the Slănic Valley, deposits belonging to the Paleogene-Quaternary stratigraphic interval appear.

The main types of rocks that appear in the rock salt deposit are: rock salt, volcanic tuffs, clays, marls and sandstones.

The rock salt, in the deposit, appears in the form of stratiform deposits of white color, alternating with bands of gray salt. The color change indicates the change in the precipitation conditions, both due to climatic variations and the terrigen input, more or less abundant.

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vol. 31, issue 1 / 2025
pp. 12-29

From a tectonic point of view, the deposits within the perimeter are located in a large Miocene syncline (the Slănic syncline), being located in its northern part over the Paleogene formations of the Homorâciu spur.

The lower and middle Miocene formations, oriented NE-SW, are located between two major fractures: the Audia line and the Cosminele fault.

The geological formations within the perimeter were separated, according to their hydrogeological behavior, into three types: permeable formations in which permanent aquifer layers develop; permeable and semi-permeable formations in which seasonal aquifer accumulations develop; impermeable formations without important aquifer accumulations.

The barren rocks from the roof of the rock salt massif, are generally represented by clayey rocks, with a low porosity coefficient. Sandy marls, clayey or sandy loams allow poor water circulation.

Mineralogically, the rock salt from Slănic consists of halite (NaCl), in a proportion of over 90% and, subordinately, of: anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2 \cdot H_2O$), kieserite ($MgSO_4 \cdot 2 \cdot H_2O$), glauberite [$Na_2Ca(SO_4)_2$] and clay substances. The existence of hematite, quartz, marcasite, pyrite, chalcopyrite, blende, dolomite was also reported in the Slănic rock salt [1], [2], [3], [4], [5].

Petrographically, the rock salt from Slănic is presented in the form of an aggregate of crystals that form a compact, grainy mass. Large crystals are linked together by smaller crystals, which form a cementing mass. The contact surfaces between the crystals have an irregular shape, which greatly increases their cohesion and adhesion.

1.2. Geomechanical characteristics

Over time, for the Slănic Prahova rock salt deposit, several test campaigns were carried out in order to determine the geomechanical characteristics of the rock salt, starting with those carried out by prof. M. Stamatiu [6, 7] and continuing with those carried out by ICEMIN Bucharest, the Mine Institute / University of Petroşani and ICPM SA Cluj-Napoca [8].

During the years 1950-1955, for the Unirea Mine, Professor M. Stamatiu [6], [7] carried out a series of determinations of the geomechanical characteristics of the rock salt.

In 2012, in the reference [9], a team of researchers from the University of Petroşani carried out a series of determinations of the geomechanical characteristics, on salt samples collected from the Cantacuzino mine, from horizon XI and from the incline, from horizons XII – XIII.

In 2022, the University of Petroşani carried out a study [10] on the geomechanical characterization of the rock salt massif, below +200 m level, in order to exploit horizons XIV and XV, from Slănic Prahova Saline. From the two preparatory galleries with a length of approx. 1,200 m, located at the XIV horizon (elevation +148m), samples were taken from the drills executed in 24 locations, placed at intervals of approx. 50 m.

Table 1. The ranges of variation of the main average geomechanical characteristics, at Slănic Prahova Saline, elevation +148 m, under the Cantacuzino Mine, Old Mines and Victoria, used in the analytical and numerical calculations [10]

Characteristic	***Cantacuzino Mine***	***Old Mines***	***Victoria Mine***
Elasticity modulus E, 10^3 kN/m^2	$2{,}700 \div 3{,}100$	$2{,}300 \div 4{,}200$	$2{,}000 \div 3{,}700$
Poisson's ratio, ν	$0.20 \div 0.29$	$0.22 \div 0.31$	$0.26 \div 0.29$
Cohesion C, kN/m^2	$1{,}600 \div 2{,}100$	$1{,}700 \div 2{,}900$	$1{,}300 \div 2{,}200$
Internal friction angle φ, °	$19 \div 22$	$19 \div 24$	$20 \div 23$
Compressive strength σ_{rc}, kN/m^2	$20{,}000 \div 23{,}000$	$11{,}000 \div 19{,}000$	$10{,}000 \div 17{,}000$
Tensile strength , σ_t	$1{,}000 \div 1{,}400$	$600 \div 1{,}100$	$600 \div 1{,}100$
Shear strength τ_{rf}, kN/m^2	$3{,}500 \div 4{,}200$	$3{,}100 \div 4{,}500$	$2{,}500 \div 4{,}400$

2. Exploitation of the rock salt deposit from Slănic Prahova Saline

2.1. The evolution of the exploitation of the rock salt deposit

The exploitation of rock salt in Slănic began in the mine in the form of a "bell", being mentioned for the first time in documents authenticating the purchase of the "Slănic estate" by the nobleman Mihail Cantacuzino, in the years 1665 and 1669. Between the years 1689-1691 he opened the exploitations from Baia Baciului. These exploitations, being close to the surface, colapsed, leading to the formation of the salty lakes: Baia Verde, Baia Baciului, Lacul Mare, Grota Miresei and Baia Porcilor [1], [2], [3], [4], [5].

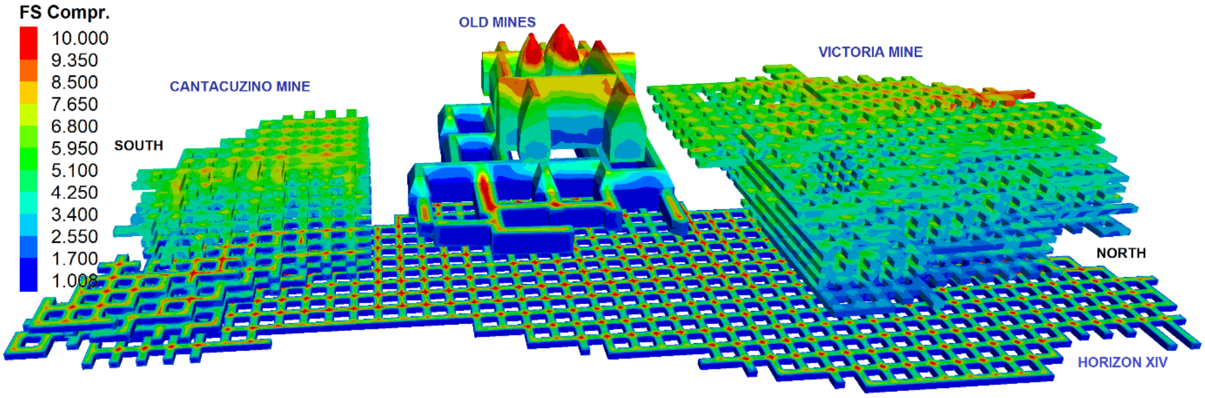


Fig.1. Spatial representation of the exploitation of Slănic Prahova Saline (the safety factor calculated by numerical modeling - the situation in 2059) [10]

The exploitation of rock salt continues in the Sistematica mine, during the years 1865-1875, through the "systematic, multi-chamber" mining method, which led to the extraction, in the time interval 1665-1875, of a total amount of rock salt of over 1.2 million tonnes [1], [2], [3], [4], [5].

In 1881, downward mining of the Carol Mine began in chambers with an ogival profile, with a height of 97 m and an opening to the base of 48 m, from which approx. 3.6 million tonnes of rock salt was mined. At the same time as the Carol Mine, in 1912 the mining of the Mihai Mine began, in large chambers with a trapezoidal - rectangular profile, with a ceiling opening of 12 m, with walls inclined at 60°, a length of 30 m, a height of 66 m and an opening at the base of 37 m, from which almost 1 million tonnes of rock salt were extracted. The Mihai Mine was one of the most modern mines at that time, thanks to the electric lighting, which was introduced since the opening, and the chain saw machine and the blasting of the rock salt with explosives, starting in 1931 [1], [2], [3], [4], [5].

In continuation of the mentioned mines, under a 28-31 m thick safety ceiling, the Unirea Mine, exploited in the years 1942 and 1970, is developing in depth. The Unirea Mine is a set of chambers with a trapezoidal-rectangular profile, arranged around a central pillar. The chambers have a ceiling opening of 10 m, walls inclined at 60°, a length of 30 m, a floor opening of 35 m and height of 56 m and a total volume of excavated rock salt of almost 3 million m^3. After the cessation of exploitation, the Unirea Mine operates as a tourist attraction.

Between the years 1970-1992, the Victoria Mine was exploited in Slănic, from where more than 15.5 million tonnes were extracted. Here, the mining method was applied with small rooms and square pillars, on 11 overstory horizons, separated by safety ceilings with a thickness of 8 m. The intercameral pillars with a square horizontal section, with a side of 14-17.5 m and a height of 8 m, are arranged coaxially vertically, and the rooms have a span of 16 -12.5 m [1], [2], [3], [4], [5].

In the period 1990-2022, south of the Old Mines, approx. 5 million tonnes of rock salt from the Cantacuzino Mine were exploited. Here the mining method was applied with small rooms, square pillars and straight ceiling, between horizons V and VII, and starting from horizon VIII, the same method was applied, but with vaulted ceiling rooms. The dimensions of the pillars increased with depth, as follows: for horizons V - VII, L_p = 16 m; for horizons VIII – X, L_p = 17 m; for the XI horizon, L_p = 18 m.

Because the exploitable reserves of the Cantacuzino Mine, located above the level of +193 m, were exhausted in 2019, the mining activity continued below the level of +193 m, starting from the XIV horizon, located under a crown equalization pillar, with a thickness of approx. 40 m. Here the same mining method is applied with small rooms, square pillars and vaulted ceiling, with the following sizes of the pillars: L_p=18 m, in the area located west of the alignment of pillars K5 - K47; L_p=19 m, in the area located east of the alignment of pillars K5 - K47 [5].

2.2. Exploitation mining method of the XIV and XV horizons

The principle of the mining method is that the surface of the exploitation field is divided into a square grid of 30 m x 30 m, in the axes of which the center of the pillars is located, the sum of the width of the rooms and the pillars being equal to 30 m [11], [12], [13], [14], [15], [16]. The grid dividing the exploitation fields is superimposed on different levels, so that the pillars are coaxial after the vertical. As the excavation descends, level by level, the sizes of the pillars increase and the sizes of the rooms decrease accordingly. The height of the pillars/rooms on one level is 8 m. The rooms/pillars are separated vertically by 8m thick ceiling, so the height of one level is 16 m (table 2 and fig.2).

vol. 31, issue 1 / 2025
pp. 12-29

Table 2. The main geometric characteristics of the rooms and pillars from the XIV and XV horizons [17]

Specification	**Horizon XIV**		**Horizon XV**	
	East*	***West****	***East****	***West****
Rooms span, l_c (m)	10	11	9	10
Pillar sizes, l_p (m)	20x20	19x19	21x21	20x20
Ceiling size, h_p (m)	8			
Crown pillar size, h_e (m)	40			
Note: ** compared to alignment K5-K47*				

The exploitation of the XIV level begins under a crown pillar, with a thickness of approx. 40 m, built between elevations +193 m and +153 m. We mention the fact that, based on the stated principle of the establishment of mining method, this equalization ceiling consists of a portion of 8 m thickness, (between elevation +161 m and elevation +153 m) which is included in the calculation of the indicators of the mining method, as an exploitation ceiling and a portion of 32 m, which constitutes losses of the main safety pillars [17].

The exploitation field on the XIV level (fig.3), with a total area of over 43 thousand m^2, is divided into 3 exploitation subfields by 2 transversal barrier pillars, oriented east-west, with dimensions of 25x400 m, respectively 25x250 m. Similarly, the surface of the XV level, with the value of 41 thousand m^2, is delimited in 3 exploitation subfields, by 2 barrier pillars with a width of 25 m. These mining pillars are arranged under the pillars between Cantacuzino Mine, Old Mines and Victoria Mine [17].

With a view to mechanized exploitation of the rock salt with the Sandvik MT 520 roadheader, the extraction of the exploitation field from the XIV and XV level is programmed to retreat, in two successive slices (slice I, with a thickness of 5m; slice II, with a thickness of 3m), starting from the northern limit towards the southern limit. For this, on the XIV floor, at +148 m elevation, two conjugate preparatory galleries were executed by drilling and blasting technology, with lengths of 1,271 m and 1,440 m, respectively, and a cros-section of 9m/5m [17].

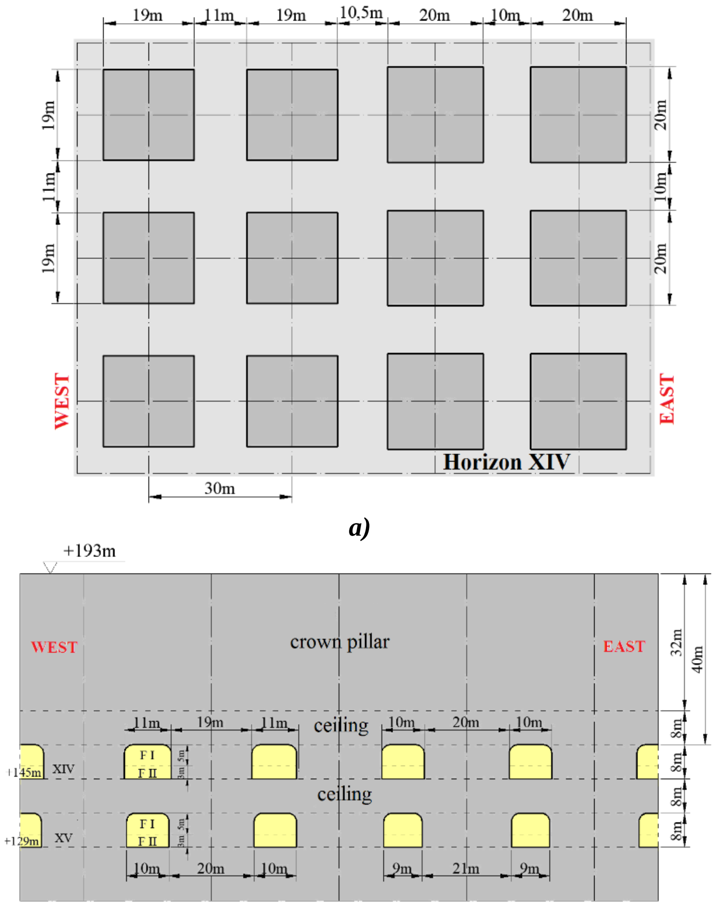


Fig. 2. The principle representation of the mining method applied to the XIV and XV level [17]
a) horizontal projection of the XIV horizon; b) east-west vertical section through the XIV and XV horizons

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590

vol. 31, issue 1 / 2025
pp. 12-29

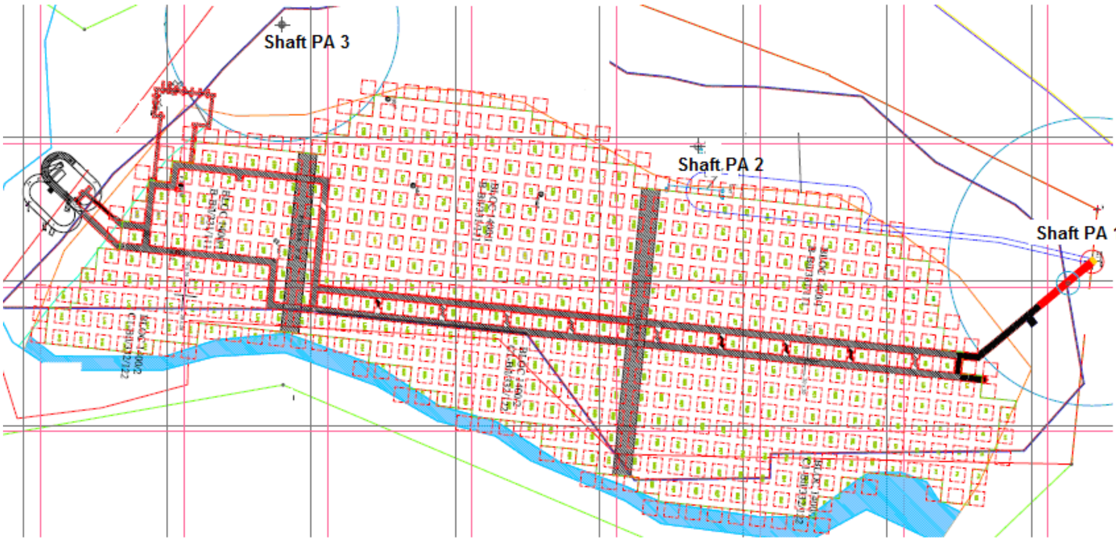


Fig. 3. Preparation and exploitation scheme of the XIV horizon [17]

The preparation of the mining field with conjugate preparatory galleries was necessary to make the connection of the auxiliary ventilation of the preparatory drifts, to the ventilation system under the general depression of the mine, represented by the three main circuits (fig.4). After connecting the preparatory workings from the XIV level to the ventilation shaft PA 1, it will be possible to proceed with the successive exploitation, in retreat of the rooms, from north to south. The rooms will be ventilated with the aid of auxiliary forced ventilation systems.

On the last section of the ventilation gallery, at the intersection with the ventilation shaft PA1, the chamber of the general ventilation station is set up, which includes a group consisting of three axial fans HGT - 160-6T/9-100 IE3 - in ANTIEX construction, placed in parallel. The cumulative airflow of the three main fans has the value of 177.3 m^3/s and is 22.7% higher than the maximum value of the calculated airflow, of 144.39 m^3/s [17], [18], [19], [20], [21].

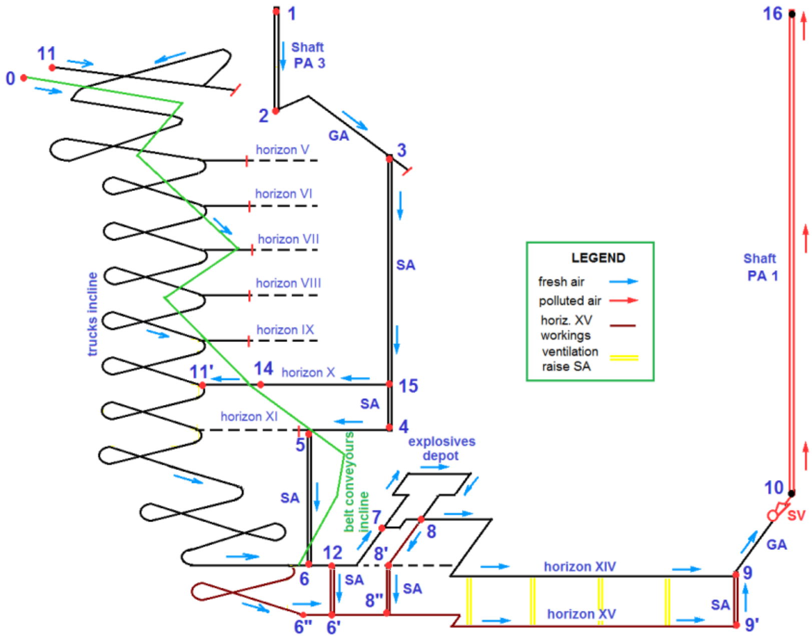


Fig. 4. Spatial monofilar ventilation scheme of Slănic Prahova Saline [17]

As for the preparation of the XV level, after connecting it through a trucks incline, (excavated between the XIV and XV horizons), this will be done through a single directional preparatory gallery of mechanized dug with the Sandvik MT 520 roadheader, at the floor level of the first slice, of +132 m. In order to achieve the ventilation of the preparatory drift, between horizons XV and XIV, at intervals of a maximum of 200 m, 7 ventilation raises, 8 m of long, will be accomplished. The raises will connect the drift to the general ventilation system of the mine, through the preparatory gallery from oriz. XIV. That gallery will remain in operation, until its connection with the ventilation shaft PA 1, located at the northern limit [17].

After the exhaustion of the industrial reserves from the first slice of the XIV level, the exploitation of the second slice, located at the level of the floor +145 m, will be carried out, by deepening with the roadheader of the preparatory galleries, by 3 m, followed by the mining of the rooms, from the north to south. The same will be done on the XV level, when the second slice will be exploited, from the level of the floor +129 m [17].

3. Rock salt mining technologies

The exploitation of the rock salt deposit at Slănic Saline, below +193 m elevation, respectively at the level of horizons XIV (+145m) and XV (+129m) is planned to be carried out at a production capacity of 220,000 tonnes/year, of which 20,000 tonnes/year in the form of lump rock salt. Then the production capacity obtained from Slănic Saline from horizons XIV and XV will be divided into the two technologies, as follows [17]:
- 180,000 tonnes/year of rock salt with a particle size below 0-0.15m, produced with the roadheader cutting technology;
-20,000 tonnes/year, rock salt with a granulometry of less than 0-0.15m, obtained with the drilling-blasting technology;
- 20,000 tonnes/year, lump rock salt with a granulometry of over 0.15-0.5 m, made by drilling-blasting.

The geometric characteristics of the vaulted ceiling rooms (fig.5) that will be applied to the exploitation of horizons XIV and XV are summarized in table 5.

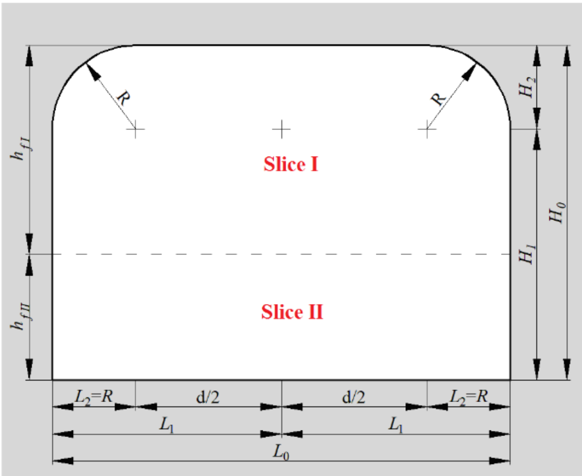


Fig. 5. Schematic representation of the profile of the cross-section of the vaulted rooms extracted in two slices, from horizons +145m and +129m [17]

Table 5. The geometric characteristics of the vaulted mining roomss from +145m and +129m horizons [17]

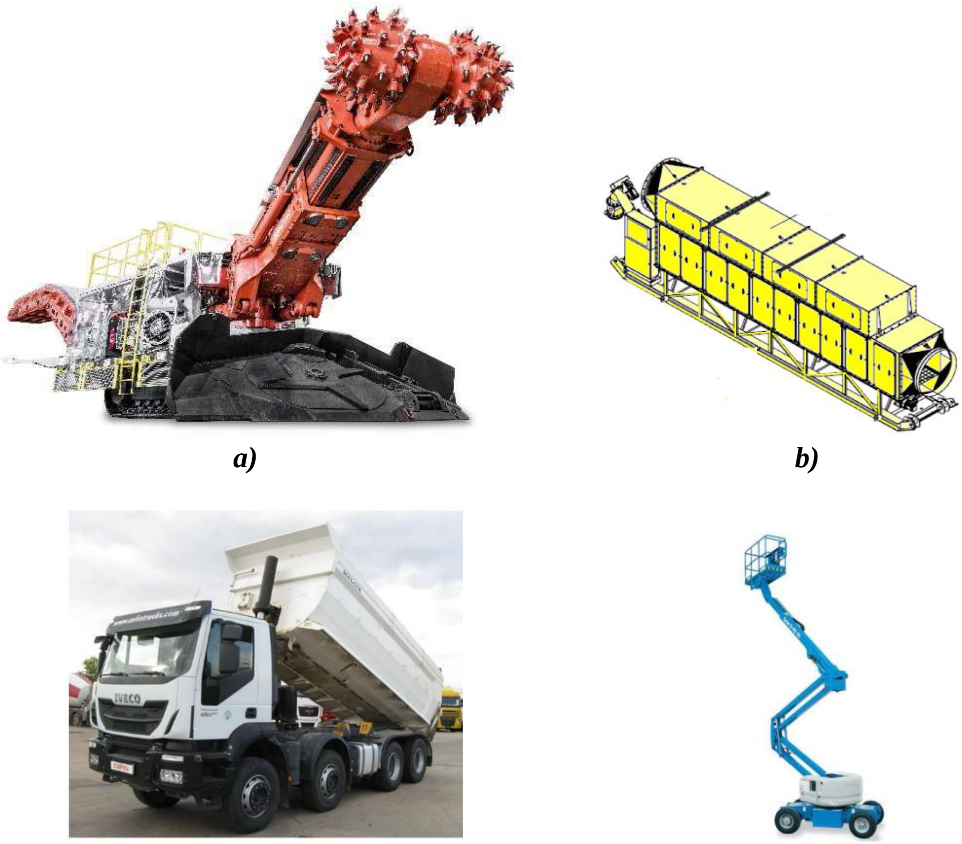
Room parameter	MU	Rooms sizes L_o / H		
		11/8 ***Horizon +145m***	**10/8** ***Horizon +145m Horizon +129m***	**9/8** ***Horizon +129m***
Cross-section area	m^2	86.28	78.28	70.28
$h_{f\mathrm{I}}$	m	5	5	5
Cross-section area – slice I	m^2	53.28	48.28	43.28
$h_{f\mathrm{II}}$	m	3	3	3
Cross-section area-slice II	m^2	33.00	30.00	27.00
H	m	8	8	8
H_1	m	6	6	6
H_2	m	2	2	2
L_o	m	11	10	9
L_1	m	5,5	5,0	4,5
L_2=R	m	2	2	2
d	m	7	6	5
d/2	m	3.5	3.0	2.5

 vol. 31, issue 1 / 2025
pp. 12-29

3.1. The mining technology of rock salt with roadheader

The roadheader mining technology will be applied for a production capacity of 180,000 tonnes/year obtained from the rooms of the XIV and XV horizons and from the opening and preparatory mining workings dug into the rock salt massif.

In equipping the mechanized digging technology with the aid of the roadheader, the following machines and equipment will be used (fig. 6): roadheader with partial attack Sandvik MT 520; DVS 21 deduster plant; IVECO MTG C4 dump truck; GENIE Z 45/25J nacelle.



a) ***b)***

c) ***d)***

Fig. 6. Machinery and equipment equipped with mechanized digging technology using the combine:
a) roadheader Sandvik MT 520; b) DVS 21 deduster;
c) IVECO MTG C4 dump truck; d) GENIE Z 45/25J nacelle

In the case of the cutting technology with the roadheader, the exploitation of the rooms takes place in 2 successive slices (the first slice and the second slice) with a height of 5 m and 3 m, respectively. Each slice with a height of 5 m/3 m, from each room (with a total height of 8 m and a width of 9, 10 and 11m) is extracted in 2 vertical strips: the first strip with a width of 6 m; respectively the second strip with a width of 3, 4 and 5 m [17].

The roadheader extracts the working front, from a single position, in the form of a circular arc with a length of 6.3 m, and the rotation angle, left-right, in the horizontal plane, of the cutting crown is 31.5^o (fig.7).

The technological process of making the first strip, corresponding to the cross-section of a room, includes the following cutting phases [17]:

Phase 1: From the stationary position of the roadheader, centered on the axis of the 6 m x 5 m strip, the cutter head penetrates the salt massif at one of the ends of the strip, on a width of 2.38 m and a depth of 0.625 m;

Phase 2: The cutting of the horizontal strip continues with the movement of the cutter head in the horizontal plane, up to the right extremity of the front, making a strip at the hearth, over the entire width of 6 m of the exploited strip, along the length of the circular arc of 6.3 m;

Phase 3 and 4: After extracting from the floor a strip with a height of 1.25 m, the vertical extraction of a portion of the front with a width of 3.0 m continues, by moving the cutter head in a vertical plane with left-right movements on 20-30 cm.

vol. 31, issue 1 / 2025
pp. 12-29

Phases 1, 2, 3 and 4 are also repeated at the level of the 2nd strip from the 1st slice, with a width of 3 m. After making a steep of 0.625 m, the roadheader advances, centers on the new position, and the cycle repeats (fig.8).

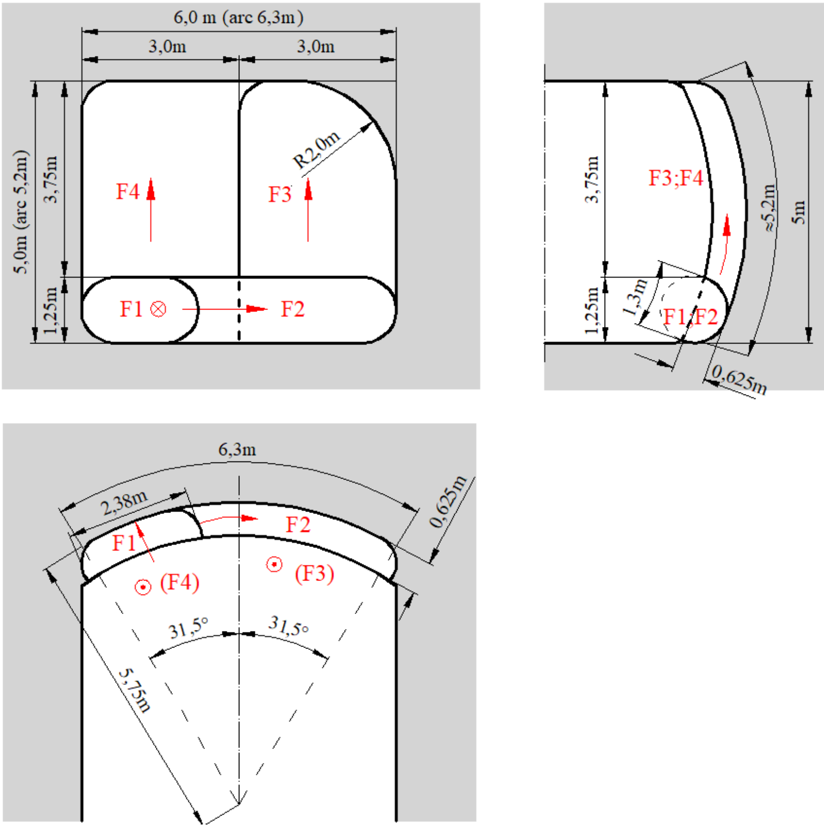


Fig. 7. Representation of the main cutting phases with the roadheader of the 6 m x 5 m strip, of the rooms in slice I [17]

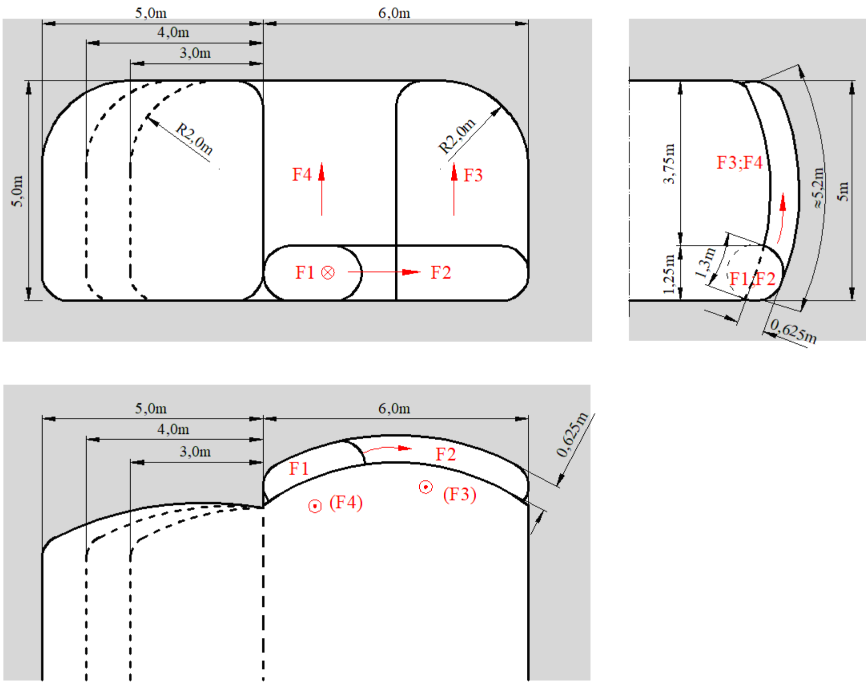


Fig. 8. Extraction with the roadheader of the second strip, of the rooms from the first slice [17]

In a similar way, the mining of rock salt takes place with the combine in front of the rooms, from the second slice (fig. 9).

vol. 31, issue 1 / 2025
pp. 12-29

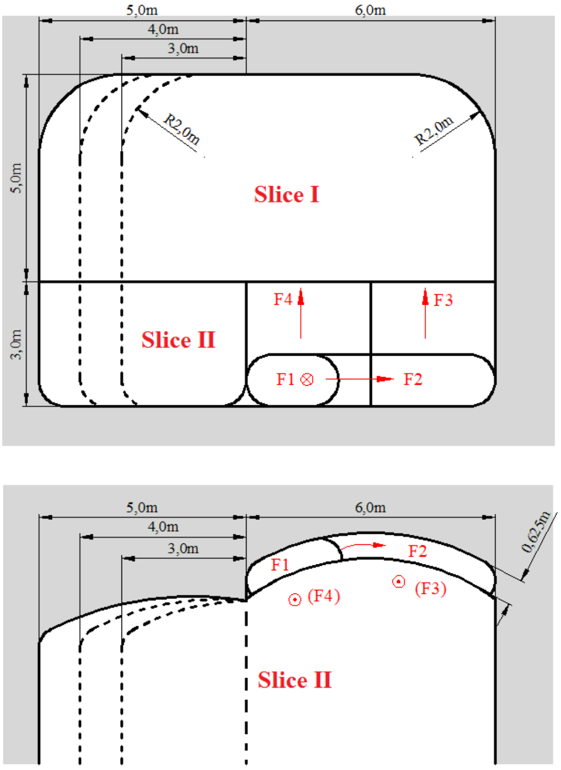


Fig. 9. The roadheader extraction of the second slice,
from the exploitation room from horizons XIV and XV [17]

3.2. Drilling-blasting mining technology

The drilling-blasting mining technology will be realized for a production capacity of 40,000 tonnes/year, of which 20,000 tonnes/year is rock salt in the form of lumps.

Excavation using the drilling-blasting mining technology of the rooms, for the production of lump rock salt, is carried out by cutting with explosives placed in ordinary mine holes, in steps of 1.6 m. The charging of the holes and the triggering of the explosion are carried out after cutting with the aid of the URAL-33 chain saw machine a channel at the floor of the mining working, with a depth of 1.9 m and a thickness of 0.15 m.

After ventilating the working and scaling the ceiling and walls of the workings, the technology continues with the removal of the crashed material with the 921G Case front loader, loading into IVECO MTG C4 dump trucks and transport to the chute/bin that feeds the belt conveyor system.

The following machinery and equipment will be used in equipping the drilling-blasting mining technology: SANDVIK DD411 jumbo (fig.10.a); Ural-33M chain saw machine; 921G CASE wheel loader (fig. 10.b); IVECO MTGC4 dump truck (see fig.6.c); the GENIE Z 45/25J car nacelle (fig. 6.d).

a) ***b)***

Fig.10. Machines and equipment for the mining technology of extracting lumps rock salt
a) SANDVIK DD411 jumbo; b) 921G CASE wheel loader

In the case of rock salt blasting at Slănic Saline, 30 MM SED millisecond detonators (with a delay of 30 ms between steps) are used.

Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590

vol. 31, issue 1 / 2025
pp. 12-29

In the drilling-blasting monographs for the mining rooms, from where the lumps rock salt will be extracted, 5 micro-delay steps were used - from 0 to 120 ms (for the 1st slice) and 3 delay steps - from from 0 to 60 ms (for the second slice), at intervals of 30 ms. We mention that the drilling-blasting monographs specific to the extraction of lumps rock salt were established by reducing by approx. 30-35% of the total amount of explosives, specific to the monographs for the exploitation of rock salt from Salina Slănic Prahova.

According to the drilling-blasting monograph [22], [23], [24], [25], [26], [27], the main parameters (for a step of advancement) are the following:

a) for the 1st slice (fig.11): the total amount of explosive, 42 kg; specific explosive consumption, 0.247kg/t; total hole length, 76.98 m; hole specific consumption, 0.453 m/t. When the mining front is advanced by one step, a quantity of 169.95 t is obtained;

b) for the second slice (fig.12): the total amount of explosive, 26 kg; specific explosive consumption, 0.246kg/t; total hole length, 48.48 m; hole specific consumption, 0.459 m/t. When the mining front is advanced by one step, a quantity of 105.6 t is obtained.

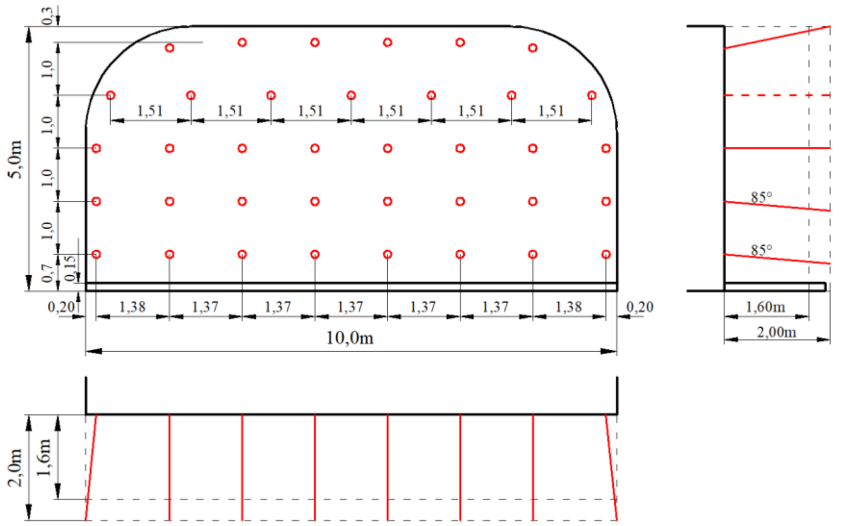


Fig. 11. The scheme of location of the holes when digging the 10 m wide rooms– slice I, horizon +145m and +129m (S=48.28m^2), for the production of lumps rock salt [17]

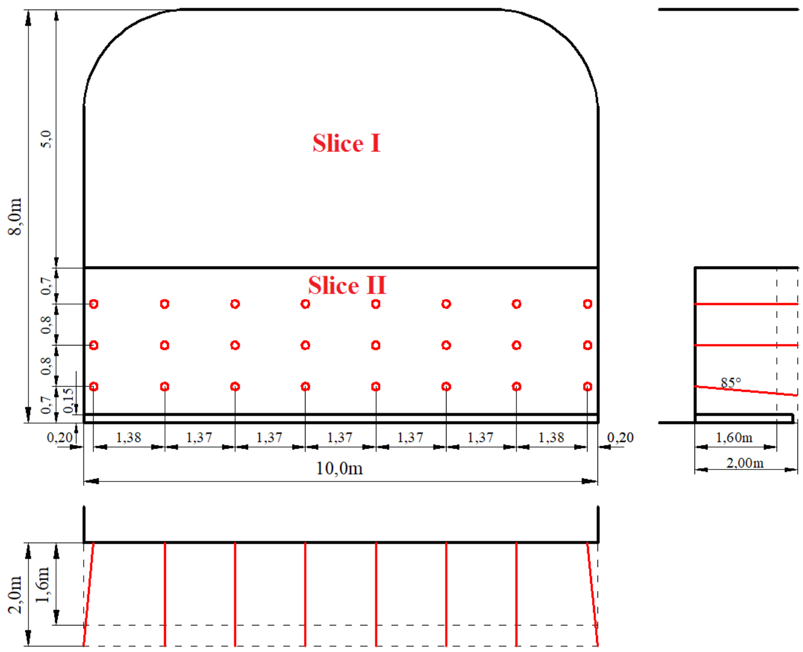


Fig. 12. The scheme for the location of the holes when digging the 10 m wide rooms – second slice, rice +148m and +129m (S=30 m^2), for the production of lumps rock salt [17]

vol. 31, issue 1 / 2025
pp. 12-29

4. Checking the dimensions of the resistance structures (rooms, pillars and floors)

The technological parameters of the mining method refer to the dimensions of the rooms and resistance structures (exploitation pillars and floors) within the exploitation field, from the level of the XIV and XV horizons.

The values of these parameters were established by MINESA ICPM SA Cluj Napoca in the study [5] and were taken over in the documentation for the extension of the exploitation license [4]: the width of the rooms being set at the value of 12 m and 11 m, for the XIV horizon and for the XV horizon, and the thickness of the ceiling between the two horizons having the value of 8 m. The two horizons are located at an elevation of +145 m and +129 m respectively, under a crown pillar with a thickness of 40 m, between an elevation of +193 m and an elevation of +153 m [4], [5].

Following the stability studies of the rooms and resistance structures carried out by the University of Petroșani [10] it was established that the dimensions of the pillars, mentioned above, are undersized, because the safety coefficients calculated by analytical and numerical methods are at the stability limit. As a result, it resulted in the recommendation to increase the dimensions of the sides of the pillars by 1 m, at the XIV horizon and by 2 m, at the XV horizon, which led to the values of the geometric parameters summarized in table 2.

With the new values of the dimensions of the rooms, pillars and ceilings, a verification by analytical and numerical methods and a stability analysis, by the method of finite element (2D and 3D), of the resistance structures, focusing on the inter-camera pillars, was carried out.

4.1. Checking the dimensions/stability of mining rooms, pillars and floors by analytical methods

For the rock salt mines that have reached or will reach a relatively high depth of exploitation, as is the case of the Salina Slanic Prahova, it is necessary to establish the safety depth, i.e. the depth from which deep exploitation becomes difficult due to the increase in the degree of instability.

The calculation of the limit depth for exploitation at Slănic Saline was carried out according to [9, 10]: the gravity load criterion (limit depth is 442 m), according to Fenner's theory (381 m) and according to the creep behavior of rock salt (452 m).

Depending on the rheological behavior of the rock salt from Slănic Prahova, 3 creep zones were identified, for which the states of long-term stability, relative stability and instability of the rock salt were defined [9, 10]:

Zone I: for the depth $H < 253$ m, elastic behavior of the rock salt massif – *of unlimited stability*;

Zone II: for the depth H=253-452 m, elasto-plastic behavior of the rock salt massif - *of relative stability*;

Zone III: for the depth m, plastic and visco-plastic behavior of the rock salt massif - *of instability*.

Taking into account the fact that the current depths at Slănic Prahova Saline are a maximum of 380 m, for the XIV horizon (+145 m) and 396 m, for the XV horizon (+129m), this critical depth of 452 m, from which the underground excavations will be affected by instability, it will not be reached in the near future [17].

Analytical calculation methods, used in the stability analysis of rooms and resistance structures (pillars and ceilings) - some of them, used since the beginning of modern mining of the exploitation of rock salt deposits, in the conditions of rock salt mines in Romania and abroad. These established analytical methods are generally based on the theory of elasticity and plasticity, taking into account the assumptions of plane strain (when the strains perpendicular to the plane of analysis are considered equal to zero) and plane stresses (when the stresses perpendicular to the plane of analysis are considered equal with zero), simplifying hypotheses, which aimed to reduce a problem in 3-dimensional space (impossible to solve analytically) to a planar, much simpler problem in 2 dimensions [28].

The dimensions of the leveling floor, chambers and piers of horizons XIV and XV (see table 2) were established by the mentioned analytical dimensioning methods, used over time, by various design engineers and researchers, from specialized institutions in the mining field, in various studies and projects. That is why the analysis of the stability of the resistance structures was done taking into account the verification calculation, for the determination and analysis of the safety coefficients and the duration of existence of the studied structures.

Consequently, the analytical verification calculations regarding the stability of the rooms were carried out for the most unfavorable situation, respectively for rooms with an opening of 11 m, square pillars with dimensions of 19 m x 19 m, at the level of the XIV floor and for rooms with an opening of 10 m and pillars of 20m x 20m, for the XV floor and the maximum depth from the surface of the hearth horiz.+145m, of H=380 m. Since the XIV and XV floors will be exploited in two horizontal slices with a thickness of 5m, the first slice and with a thickness of 3m, the second slice (under the conditions of cutting the salt with the combine), the stability analyzes were carried out for rooms with the height of 5m, then for the same rooms, with a height of 8m.

With the help of analytical calculation methods [14], [15], [29], [30], [31], [32], [33], [34] the following were checked: a) the stability of the rooms in terms of their opening to the ceiling (with Ritter and Protodiakonov's methods), the length of the rooms (with Borger's method) and the height chambers (with the Coulomb-Rebhann method, in two calculation hypotheses); b) the stability of the pillars (with the methods of Ševiakov, Sokolovsky-Ruppeneit, Ruppeneit, Stamatiu); c) the stability of the leveling slab (by assimilating them with embedded slabs, slabs subjected to shearing, with the algorithms of Ennour and Coates). The summary of the results of these verification calculations (safety factor and lifetime) and the main geometric and geomechanical calculation parameters is presented in the table below.

Table 6. Centralizing table with the results of the analytical methods for verifying the stability of the rooms, pillars, ceilings and crown pillar from XIV and XV horizons, Slănic Prahova Saline [17]

Calculation procedure	Geometric characteristics	Geomechanical characteristics	Safety coefficient	Lifetime, years
A. CHECKING OF ROOMS STABILITY				
A1. Opening to the ceiling of the rooms				
W. Ritter	L_c	σ_t	XIV: L_c=11 m; n=21.0	Very big
			XV: L_c=10 m; n=23.0	
M.M. Protodiakonov	L_c	σ_t	XIV: L_c=11 m; n=35,6	Very big
			XV: L_c=10 m; n=39.1	
A2. Rooms length				
H. Borger	L_c, L	σ_f	22.0	Very big
A3. Rooms length				
C.A.Coulomb-G.Rebhann Hypothesis I	L_c, h_c	$\varphi, \sigma_t, \sigma_f$	h=5 m: n=11.43	Very big
			h=8 m: n=7.14	
C.A.Coulomb-G.Rebhann Hypothesis II	L_c, h_c	$\varphi, \sigma_t, \sigma_f$	h=5 m: n=28.6	Very big
			h=8 m: n=17.7	
B. CHECKING OF PILLARS STABILITY				
L.D. Şeviakov	L_c, L_p, h_p, H	σ_c	n=1.1-1.7	<2.7
V.V.Sokolovsky - K.V.Ruppeneit	L_c, L_p, h_c, h_p	$C, \varphi, \sigma_c, \sigma_t$	XIV: n=5,27	>20
			XV: n=6,07	
M. Stamatiu	L_p, h_p, H	φ, σ_c	h=5m: XIV: n=5,8 XV: n=6.26	>20
			h=8m: XIV: n=2.27 XV: n=2.45	<2.7
C. CHECKING OF CROWN PILLAR STABILITY				
Assimilated ceilings with double embedded beams	L_p, h, H	σ_t	n = 5.8	>70
D. CHECKING OF CEILING STABILITY				
Assimilated ceilings with embedded plates	L_c, h	σ_t	n=14.2	>70
Ceilings subjected to shear	L_c, L_p, h	C, φ, σ_c	n=11.0	>70
Ennour's algorithm	L_c, h_c, H	C, φ, ν	n=28.8	>70
Coates's algorithm	L_c, h	σ_c, σ_t	Shear: n=11.74 Tensile: n=6.77	>70
NOTES: L_c-room width ; L_p-pillar width; L-room length; h_c-room heigth; h_p-pillar heigth; h-ceiling thickness; H-mining depth; C-cohesion; φ -internal friction angle; ν -Poisson's ratio; σ_c - compressive strength; σ_t - tensile strength; σ_f - shear strength				

vol. 31, issue 1 / 2025
pp. 12-29

Following the analysis of the safety factors, summarized in table 3, it can be found that their values exceed their acceptable limits, for reasonable lifetimes of the calculated structures, less in terms of the dimensions of the pillars.

In *conclusion*, it follows that, through the mechanized cutting of rock salt with the aid of roadheader and implicitly the reduction and even elimination (in the future) of explosives in the underground works at Slănic Saline, the stability parameters of the resistance structures (pillars and ceilings) become much superior to those obtained by cutting the massif of rock salt through the drilling-blasting process.

4.2. Checking of the stability of rooms, pillars and ceilings by numerical modeling

In order to analyze the stability of the underground mining excavations and the resistance structures from the XIV and XV horizons, three representative 2D finite element numerical models were built in plane deformation hypothesis through the Victoria Mine, the Old Mines and the Cantacuzino Mine. Also, for the analysis of the stability of the rooms and resistance structures (with a focus on the pillars stability), four numerical models in 3D were made: two models with the exploited XIV horizon, the west wing and the east wing; two models with both XIV and XV horizons exploited, the west wing and the east wing, respectively.

In the stability calculations, an elasto-plastic behavior law Mohr-Coulomb type without hardening was chosen [9, 10, 17, 28]. In the case of 3D models, in order to obtain much more detailed calculation results, by increasing the number of elements, only 4 pillar columns and the related mining rooms, loaded with the representative geostatic rock column for the greatest depth, were studied of the two horizons in operation.

Carrying out the analysis with finite element in 2D, in plane deformation, and 3D, for the models defined above, required the following stages: I) establishing the limits, the area of interest and the discretization of the model; II) determination of areas (regions), calculation hypothesis and introduction of geomechanical characteristics; III) imposing of boundary conditions; IV) establishing the initial and loading conditions of the model; V) making calculations and storing the results [28, 36].

The dimensions of the areas of interest around the underground excavations were determined in such a way as to include the surface / volume of the model where the variation of stresses and deformations is maximal. The discretization of the 2D models, respectively of each region separately, was achieved by triangular surface finite elements with quadratic interpolation. Regarding the discretization of 3D models, the model discretization elements, respectively the total number of nodes and volume elements.

To simplify the numerical models in 2D and 3D, two regions with specific geomechanical characteristics were considered, corresponding to the surrounding rocks and the rock salt deposit (table 1 and table 7), considered to be homogeneous and isotropic and calculated with medium values.

Table 7. The main average geomechanical characteristics of the rock salt massif and surrounding rocks considered in analytical and numerical modeling

Characteristic	**MU**	**Value**	
		Rock salt	***Surrounding rocks***
Apparent density , ρ_a	kg/m^3	2,100	2,200
Apparent specific weight , γ_a	kN/m^3	21.0	22.0
Elasticity modulus , E	kN/m^2	2,900,000	3,400,000
Poisson's ratio , ν	adim.	0.28	0.21
Compressive strength , σ_c	kN/m^2	19,000	-
Tensile strength , σ_t	kN/m^2	1,200	-
Shear strength , τ_f	kN/m^2	2,500	-
Cohesion , C	kN/m^2	2,900	5,300
Internal friction angle , φ	^{o}	28	24

The initial loading conditions of the 2D and 3D models were considered geostatic [35], corresponding to variable thicknesses of the covering formations. The vertical geostatic stresses are $\sigma_{oz} = \rho_a \cdot g \cdot H$ and the horizontal geostatic stresses are $\sigma_{ox} = \frac{\nu}{1-\nu} \cdot \sigma_{oy} = k_o \cdot \sigma_{oz}$; where $k_o = \frac{\nu}{1-\nu} = \frac{0.28}{1-0.28} = 0.39$. The 3D finite element models were geostatically loaded for the critical depths measured from floor of horizon +145m, H=315 m, for the west wing and H=380 m, for the east wing.

 vol. 31, issue 1 / 2025
pp. 12-29

Although the 2D model is based on a number of simplifying assumptions, it allowed a denser discretization of the corresponding 3D models. In the same sense, in order to increase the degree of precision of the calculation results, following the increase in the number of elements, the 3D models were made only for 4 columns of pillars, respectively for 2 mining units, from the level of the XIV and XV horizons, ignoring the importance of excavations above these horizons.

Taking into account the advantages and disadvantages offered by the two types of models (2D and 3D), in the following a stability analysis of the resistance structures will be carried out, taking into account the most representative results, from a qualitative and quantitative point of view.

2D finite element modeling

The *norm of plastic deformation* (NDP) is an indicator of the entry of the massif of rock salt into a state of plastic, irreversible deformation and the onset of some accentuated phenomena of local destruction. It also highlights the plastic behavior of rock salt at a certain depth and at some excessive stresses. In fig.13 the NDP is represented scalar for a representative vertical section through the Victoria Mine, which most influences the XIV and XV horizons, where the areas around the excavations with different degrees of entry into plastic deformation can be observed.

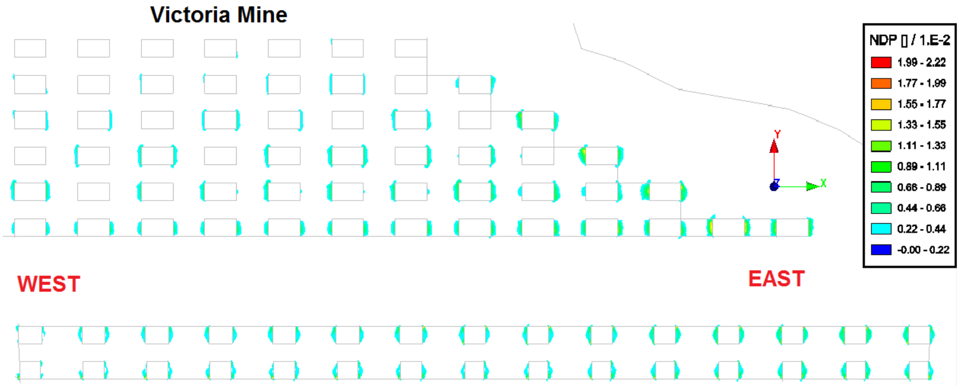


Fig.13. Plastic deformation norm NDP - scalar representation, through a representative vertical section of Victoria Mine [17]

Regarding the calculated value of *the safety coefficient* according to the Mohr-Coulomb criterion, there are three cases of stability: 1) CS=1, when Mohr's circle and the intrinsic curve are tangent - resulting in stability at the limit; 2) CS<1, when Mohr's circle and the intrinsic curve are secant - resulting in conditions for the appearance of failure phenomena; 3) CS>1, when the stress state is far from the failure phenomenon - resulting in a certain degree of stability, depending on the value of the safety coefficient [17, 28].

Figure 14 shows the variation of the safety coefficients along a significant cross-section through the Victoria Mine, through a sectioning plan in the middle of the exploitation pillars, from the XIV horizon (elevation +149 m) and the XV horizon (elevation +133m). As can be seen from these graphs, in general, the safety coefficients have values of approx. *CS*=1.2, on the outer surface of the pillars, reaching a maximum of *CS*=1.8 (for the XIV horizon) and *CS*=1.9 (for the XV horizon), in the center of the pillars. The lower values of the safety coefficients explain the degradation phenomena of the pillars towards their outside. The calculated values of the coefficients, based on the data resulting from the modeling with finite elements in 2D, are somewhat optimistic (they are higher than in reality, by approx. 30-37%) considering the fact that the modeling was carried out under the plan deformation hypothesis, having the tendency to approach the values calculated by analytical methods.

3D finite element modeling

The maximum (major) 3D (fig.15.a) and minimum (minor) principal stresses (fig.15.b) are the most representative stresses for a stability analysis, their ratio highlighting the degree of balance of the material points in the composition of the rock salt massif analyzed. Following the direction of principal stresses there are no shear stresses, only tensile and compressive stresses [10], [17], [28].

The *major principal stresses* (fig.15.a) developed in the resistance structures are, in general, compressive stresses, developed in the inter-rooms pillars and tensile stresses, in the ceilings and in the walls of the rooms. There are two local areas in the ceiling and floor of the rooms affected by tensile stresses,

Revista Minelor – Mining Revue vol. 31, issue 1 / 2025
ISSN-L 1220-2053 / ISSN 2247-8590 pp. 12-29

which have values that can exceed several times the tensile strength value of the rock salt, and where detachments from the ceiling and fracture opening/formation and/or mobilization can occur natural cracks in the floor of the rooms. Tensile wall spalling can occur in the upper and lower halves of the pillars, in the form of a band, and also in height along the pillars corners.

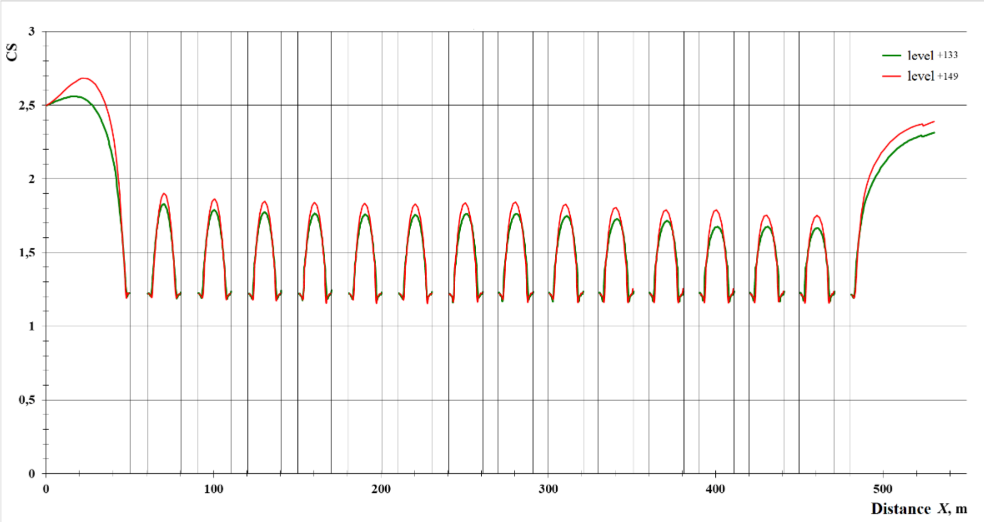
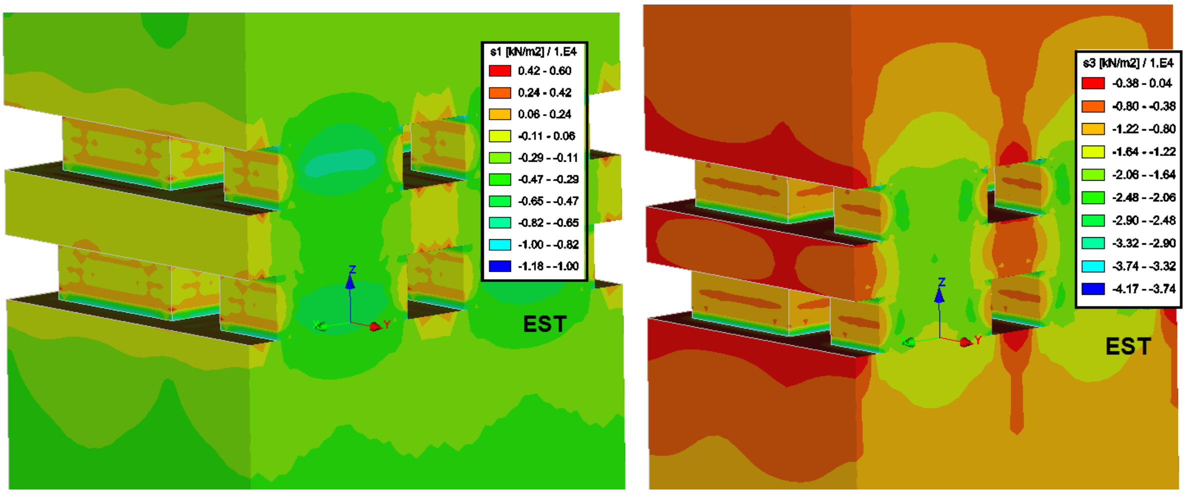


Fig. 14. Representation of the safety factors, calculated acording to the Mohr-Coulomb criterion, in a vertical section through the Victoria Mine [17]

All *minor principal stresses* (fig.15.b) in the analyzed models are compressive stresses both in the pillars and in the ceiling. Here, too, an increase in compressive stresses towards the base of the pillars and towards the upside is observed, to values that exceed the compressive strength of rock salt and which can explain the destruction of the corners and external surfaces of the pillars, starting from the border with the floor of the rooms, respectively at the border with their ceiling. Also, from the point of view of the minimum principal stresses, a relaxation of the ceiling in its middle can be found, which, combined with the increase of the maximum principal stresses, shows that favourable local conditions can be created for the appearance of ceiling degradation phenomena in these area.



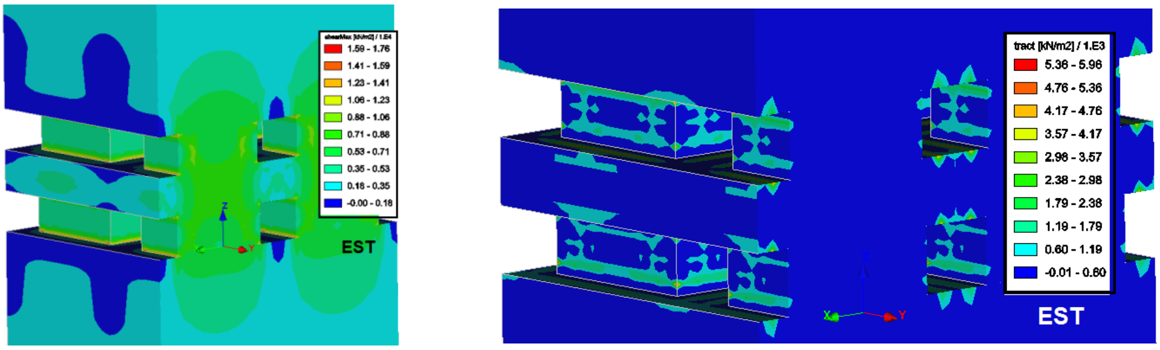
a) ***b)***

Fig. 15. Maximum principal stresses (major) σ_1 (a) andminimum principal stresses (minor) σ_3 (b) in kN/m^2 - scalar representation

The *maximum shear stresses* (fig. 16.a) indicate the structural areas where there is a potential for shearing failure in the rock salt massif or mobilization of existing cracks or natural fractures in the massif. Since the shear strength value of rock salt is quite low, approx. 2,500 kN/m^2, shear stresses, along with tensile stresses, can be the cause of most of the phenomena of degradation of resistance structures (pillars, rooms) and the occurrence of underground collapsings.

vol. 31, issue 1 / 2025
pp. 12-29

Tensile stresses (fig.16.b) primarily affect the ceilings in the floor, in two areas in the ceiling and in certain local areas at the level of the walls. The noted areas in the ceiling of the rooms are prone to rock salt detachments and the formation of two vaults, and in the floor of the rooms cracks may appear or families of pre-existing cracks/fractures may open. In the walls of the rooms, especially at the corners of the pillars, they can break, leading, over time, to the decrease of the bearing capacity of the pillars. If at the walls of the rooms the tensile stresses vary at the limit of the tensile strength of the rock salt (of 1,200 kN/m^2), at the ceiling and floor, most of the stresses exceed these values, which clearly shows the occurrence of some tensile failure phenomena in these areas marked by instability.



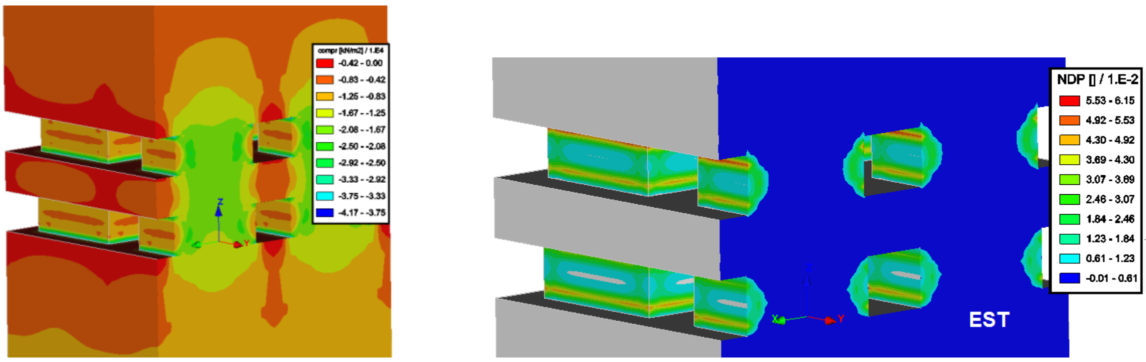
a) ***b)***

Fig. 16. Maximum shear stresses $\tau_{f\ max}$ *(a) Tensile stresses* σ_t *(b), in kN/m*^{2} *- scalar representation*

The *compressive stresses* (fig. 17.a) especially affect the inter-rooms pillars and a concentration of the compressive stresses in the pillars, at the border with the rooms, towards the outer surface, until the compressive strength of -19,000 kN/m^2 is reached.

In the ceiling, the stresses do not exceed the compressive strength value of the rock salt, which makes it stable in terms of compressive stresses.

The *norm of plastic deformation NDP* (fig.17.b) indicates the local areas in the resistance structures in a plastic deformation. We note that, in the case of these models, there are no areas of plastic deformation in the ceilings, but only in the walls of the rooms, with a concentration of about a strip in the upper and lower thirds of the walls, and to some extent towards the corners of the pillars.



a) ***b)***

Fig. 17. The compressive stresses σ_c *, in kN/m*^{2} *(a) and*
plastic deformation norm NDP-3D (b) - scalar representation

Following the analysis of the results obtained through 3D finite element modeling, respectively of the state of stress - strain of the resistance structures at the level of the XIV and XV horizons, it can be *concluded* that the general stability of the pillars and ceilings is relatively good, which makes these horizons to be functional for a limited period of time.

5. Conclusions

Slănic Prahova Saline is one of the oldest rock salt mines in Romania whose exploitation began in the middle of the 17th century through Old Mines, then continued through Victoria and Cantacuzino mines, until the year 2022.

Deep exploitation of the rock salt deposit continues below +193m elevation, under a crown pillar, 40m thick, through horizons XIV and XV, at a programmed production capacity of 220 thousand tonnes per year.

The mining method used is with small rooms and square pillars, and the mining technology is by mechanized cutting with the Sandvik MT 520 roadheader. The extraction of the production of lumps rock salt, of 20 thousand tonnes per year, is carried out by the drilling-blasting technology, adapted to the granulometry of this sort.

The sizes of the pillars and ceilings on the two mining horizons were established and checked by analytical and numerical methods using the finite element method, so that the stability of the resistance structures is ensured at least during the period of exploitation of horizons XIV (+145 m) and XV (+129 m).

The maximum limit depth, above which the rock salt has a plastic behavior, is 452m, in relation to the maximum mining depth of the XV horizon, which is 380 m, ensuring some reserve of stability for these horizons.

References

[1] **Chipeșiu F.,** 2015
Optimization of Mining Methods for Solid State Extraction of Rock Salt Deposits in Romania (in Romanian), Ph.D. Thesis, University of Petroșani.

[2] **Marina O.,** 2023
Monitoring and Analysis of Daily Ground Movements and Underground Ceilings under the Influence of Underground Exploitation of the Slănic-Prahova Rock Salt Deposit (in Romanian), Ph.D. Thesis, University of Petroșani.

[3] **Oprina C.A.,** 2015
The Possibilities of Exploitation of Rock Salt Deposits Located at Great Depths (in Romanian), Ph.D. Thesis, University of Petroșani.

[4] **Milea M. et al.,** 2018
Documentation Required for the Extension of the Exploitation License of the Slănic Prahova Perimeter, Slănic Prahova Branch (in Romanian), MINESA SA – ICPM SA Cluj Napoca, Contract no. 168/2018, with SNS SA Bucharest.

[5] **Pușcaș G. et al.** 2004
Study Regarding the Possibilities of Exploiting Rock Salt Reserves Below +200 Elevation, at Slănic Saline (in Romanian), symbol C 51-057/2004, S.C. MINESA-ICPM S.A. Cluj-Napoca.

[6] **Stamatiu M.,** 1962
Rock Mechanics (in Romanian), Didactic and Pedagogical Publishing House, Bucharest.

[7] **Stamatiu M.,** 1959
The Problem of Dimensioning Pillars in Rock Salt Mines in Romania (in Romanian), Academy Publishing House.

[8] **Arad V.,** 2008
Rock Salt Mechanics (in Romanian), Focus Publishing House, Petrosani.

[9] **Onica I., Cozma E., Hirian C., Georgescu M., Marian D. et. al.,** 2012
Technical Project - Exploitation of Salt with a Roadheder at Slănic Prahova Saline (in Romanian), Contract no. 7858/10. 07. 2012, University of Petroșani with SNS SA Slănic Prahova Saline Branch.

[10] **Danciu C., Marian D., Onica I. et.al.,** 2022
Services for the Development of a Geotechnical Study Regarding the Determination of Physical-Mechanical and Rheological Parameters in the XIV horizon of Cantacuzino Mine, in order to Estimate Its Degree of Stability, at Slănic Prahova Saline Branch (in Romanian), Contract no. 89/13.07.2022.

[11] **Almaşan B.,** 1984
Exploitation of Mineral Deposits in Romania (in Romanian), vol. II, Technical Publishing House, Bucharest.

[12] **Atudorei C., Bocanete E., Miclea P.,** 1971
Research, Exploitation and Valorization of Rock Salt (in Romanian), Technical Publishing House, Bucharest.

[13] **Covaci Ş., Oncioiu G., Cozma E., Bădulescu D., Hreniuc P.,** 1999
Mining Operations (in Romanian), Corvin Publishing House, Deva.

[14] **Deak G., Hirian C., Deak Ş., Georgescu M.,** 2005
Exploitation of Rock Salt from Romania in the 21st Century Based on Ecomining Principles (in Romanian), EXFALIA Publishing House.

[15] **Hirian C., Georgescu M.,** 2012
The Stability of Old Salines in Romania - Conditions of Their Use for Various Fields (in Romanian), Universitas Publishing House, 2nd edition.

[16] **Onica I.,** 2016
Mining Operations (in Romanian), Universitas Publishing House, Petroşani.

[17] **Onica I., Marian D.P., Toderaş M., Danciu C. et al.,** 2023
Technical Project - Exploitation of Salt at the Level of the XIV and XV Horizons in Cantacuzino Mine at Slănic Prahova Branch (in Romanian), Contract No. 30/19/10/2023.

[18] **Gontean Z. et.al.,** 1997
Computing Applications in the Design and Implementation of Mines Ventilation (in Romanian), Technical Publishing House, Bucharest.

[19] **Gontean Z. et.al.,** 1989
Mine Ventilation (in Romanian), in the Mine Engineer's Handbook, vol. V, Technical Publishing House, Bucharest.

[20] **McPherson M.J.,** 1992
Subsurface Ventilation and Environmental Engineering (in Romanian), Chapman Hall, London.

[21] **Teodorescu C. et.al.,** 1980
Mining Ventilation (in Romanian), Technique Publishing House, Bucharest.

[22] **Fodor D.,** 1986
Mining Explosives (in Romanian), in the Mine Engineer's Handbook, vol. III, Technical Publishing House, Bucharest.

[23] **Fodor, D.** (1993). *Mining Explosives* (in Romanian), Infomin Publishing House, Deva.

[24] **Letu N., Semen C.,** 1993
Mining Explosives (in Romanian), Petroşani Technical University Lithography.

[25] **Stragiotti L., Berta G. et.al.,** 1977
Lavori con esplosivo/*Working with explosives* (in Italian), Realizzato da Italesplosivo, Milano.

[26] **Tat S. et. al.,** 1985
Explosives and Blasting Technique in Industry (in Romanian), Technical Publishing House, Bucharest.

[27] **Laszlo et.al.,** 2020
Execution of Blasting Works in Salt Mines with Methane Atmosphere, Ukrainian Mining Forum 2020, Український гірничий форум Збірник 2020-282-293.

[28] **Onica I., Marian D.P.,** 2016
Applications of the Finite Element Method in the Analysis of the Stability of Ground and Underground Structures (in Romanian), Universitas Publishing House, Petroşani.

[29] **Jeremic M.L.,** 1994
Rock Mechanics in Salt Mining, Rotherdam: A. Balkema.

[30] **Ennour S.,** 1990
Modélisation des galeries de grandes largeur en terrain stratifié/Modeling of large span galleries in stratified terrain (in french), Thèse INPL, Nancy.

[31] **Hirian C.,** 1981
Rock Mechanics (in Romanian), Didactic and Pedagogical Publishing House, Bucharest.

[32] **Popescu A.,** 1973
Methods for Calculating the Stability of Underground Mining Workings and the Dimensioning of Safety Pillars (in Romanian), O.D.P.T, Bucharest.

[33] **Popescu Al., Todorescu A.,** 1982
Rocks Mechanics in Mining (in Romanian), Technical Publishing House, Bucharest.

[34] **Toderaş M.,** 2005
Geomechanics (in Romanian), Universitas Publishing House, Petroşani

[35] **Herget G**., 1988
Stresses in Rock, Rotherdam: Balkema.

[36] *****,** 2008
CESAR-LCPC, CLEO 2D and CLEO 3D - Version 4.0 – User's Manual.