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INFLUENCE OF THE PILLAR GEOMETRIC FORM OVER THE LOAD BEARING CAPACITY

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SUMMARY

The weak points arising upon parameter design of the open stope and pillars give us the challenge to overcome them developing new scientific–based, up-dated and precise methods of analysis and design. Consequently such methods are developed on the basis of profound theoretic and experimental study of the problem on the proper room and pillar measuring under specified mining and geological conditions.

Specifying the mining and geological parameters of the system, such as:width of room, width of pillar, height of pillar and the respective correlation at each separate step of the mining process, makes it possible to reach and to provide the mechanical completeness of the supporting pillar and maximal ratio volumetric.

For that purpose an adequate method of measuring of the gypsum pillars upon analysis of the geometric parameters of pillars, and particularly applying the method of the subordinated area has been suggested.

In the present study has been demonstrated a principal procedure how such a task could be accomplished under the conditions in the "Koshava" mine plant.

INTRODUCTION

Last decades are described as to have marked a considerable boom regarding the clarification of the pillar stability mechanism. Relevant to that, the problem of the proper measuring of the pillars could formally be treated as a complex decision including the solution of 2 problems.

The purpose of the first complex problem is to define in a theoretical way the pillar load bearing, going out from the accepted hypothesis.

The second purpose is related to specified empiric estimation of parameters of the collapse of pillar. To find the proper solution, numerous factors such as: strength properties of pillar, geometric parameters of pillar, flow properties, kind of contacts etc. could be the outgoing subjects.

In the present report the problem is referred as to the geometrical parameters of pillars in the open stope and pillar of exploitation.

GROUNDS OF THE PROBLEM

The exploitation of the fields and the underground equipment suppose that various pillars acting as natural support, barrier, wall of some peculiar units of the underground constructions, providing the normal functions of the mine plant. are left in the bowels of the earth.

The principal design of the pillars is to guarantee the maintenance of the works within not limited long period of time, in order to get use of them for the second time, as well as to perform a main function in the management with the rock pressure. Indeed the experience has proved that the bad influence on state of the rock massif due to blasting works, weathering and flow processes might come up upon caving after 30-years, or sometimes even earlier.

To supply a full economic evaluation of the negative consequences of such sudden collapses would hardly be possible. However in all those cases the losses of the mining plants sustained in the respective countries are reported to be quite big.

At present the underground gypsum extraction as a rule is made using the versions of the open stope and pillar of exploitation, mainly upon leaving rib pillar room fender and keeping maintenance of the mined area within not limited long period of time.

The decision on the exploitation version of the gypsum fields is believed to result from the choice of 3 factors:

- Relatively wide spread of the gypsum fields, bedding not quite deep;
- Big thickness (10-30 m) and more;
- Slope bedding of the gypsum layers;
- High resistance of the open-mining areas.

The small volume of the development and undermining cut operations, the gypsum extraction in works of big section, comparatively not difficult mining extraction /yield/ related only to the explosion breaking and carrying away the mined mass mainly by road transport, the absence of some developments of the rock pressure during the exploitation in the works – are known to be the main reasons determinant the comparatively low cost of the mined gypsum mineral.

Indeed the applied technology in the practice is going along with a number of disadvantages. As a main disadvantage are considered the big losses sustained of the mineral in the pillars (sometime reaching up to 70% of the balanced stocks) and the inevitable caving of the mined area.

The main design of the gypsum pillars left is to provide the maintenance of the works within not limited long period of time in order to get use of them for the second time. However the examinations in the practice have demonstrated that due to the bad influence of drilling and blasting operations, the weathering and the flow processes, rock caving is known to occur as early or as late. As examples could be pointed out the caving in the mine fields of Nikitovsko, Dekonsko, in Donbas, Port-Maron and Chante Le Vou in France, Koshava in Bulgaria.

The purpose is to exploit the gypsum mine in a proper way and to provide comparatively long lifetime of the extracted areas with the open stope and pillar of exploitation and to do it in a way to prevent from uncontrolled caving of the earth surface through out the years. Such an uncontrolled earth caving could last uncertain period of time while the gypsum reserves left in the pillars are in such a shape that makes the repeated stopping either not possible or economic not efficient.

All stated above proves the necessity to study the machinery and technologies of the gypsum mining and the relevant methods on parameter calculations of rooms and pillars.

SUBJECT OF THE SCIENTIFIC RESEARCH

The subject of scientific research in the present study is referred as to the analysis of the geometric parameters of pillars in “Koshava” gypsum field, by means of theoretically study of the problem on the pillar load bearing capacity and to find out an adequate method of calculation.

The gypsum environment has clearly expressed flow properties, which are to be found mainly in the behavior of pillars, put under long lasting and very often changing exertion. Several cases of considerable flow-shifts and deformations have been registered. The long –term experience of Koshava mining exploitation has pointed out that upon building of solid enough pillars,is being created a core of confinement, which can guarantee the stability of “room-supporting pillars” system. However in that case the extraction ratio drops considerably. That leads to inefficient exploitation, which finally cuts the life – time of the mine.

The technical and economic efficiency of the open stope and pillar of exploitation is closely linked to the dimensions of the pillars. The economic factors require that the technical concepts assure the most efficient extraction of the mine stocks. However the economic factors are against the requirements of maximal safety of labor, which force to work at higher safety ratio, and that provoke the enlarging of the pillar dimensions.

In table № 1 is shown the relation between the parameters of the open stope and pillar of exploitation and the appropriate losses of gypsum, left in the pillars and the protective top and floor benches in the rooms. It is obviously that in cases of gypsum extraction at the full sickness of the layer, the extract ratio is going to be increased and reaches 60-70% (the mine fields of Kamsko-Ustinsko, Gorazubovsko), (Usachenko, B.M., 1985).

The recent 100 years are rich of a number of analytic and experimental explorations carried out on the matters concerning the rock pressure in the open stope and pillar of exploitation. Some authors have developed analytic methods for evaluation of the loading and load bearing capacity of the pillars for the conditions of horizontal and sloped mine- fields. The more profound the objective law of development of the rock pressure is known, the more precise and real the evaluation of the pillar parameters will be. The investigations in the recent years based on scientific experiments in labs and industrial conditions have concentrated mostly on the digital modeling and universal study of the physic-mechanical and geological properties of the rocks. The loading and deformations of the pillars as a function of the rock pressure is said to be dependant on number of factors, such as:

- The depth of mining works;
- The correlation between the surface of pillars and rooms ;
- The composition of the covering rock layers;
- Their bending resistance;
- The composition, strength, and deformation-properties of the mineral;
- The flow properties of the rocks;
- The pillars location in the mined area.

The latest examinations on the load bearing of pillars are to be found in different works of various contemporary explorers, which are not completely generalized.

One of the most precise empiric relation expressing the effect of the volume and geometric form of the pillar toward the pillar strength is that of Hardi and Agapito(1977):

$$S = S_0 .V^a.(W_p / h)^b = S_0 .V^a .R^b$$

Referred to as follows:
V – volume of pillar, m^3;
W_p - width of pillar, m;
h - height of pillar, m;
S_0 - parameter of strength, representing the mined area, MPa;
R – correlation width of pillar toward height of pillar., (Brady, B.H.G., E.T. Brown, 1993)

The shape effect arises from three possible sources:

- Confinement which develops in the body of a pillar due to constraint on its lateral dilation, imposed by the abutting country rock;
- Change in pillar failure mode with change in aspect (i.e. width / height) ratio;
- Redistribution of field stress components other than the component parallel to the pillar axis, into the pillar domain.

ANALYSIS OF THE GEOMETRIC PARAMETERS OF THE ROOMS AND PILLARS IN "KOSHAVA" MINE PLANT

The open stope and pillar is the principal one, which the works in Koshava mine exploitations have followed from the very beginning till now. It should be highlighted that the system has been applied in different versions and that is believed to determine different behaviour and different operation conditions of the composition units: room – pillar – roof - floor. For different versions of the open stope and pillar, the versions applied are as follows:

- Various forms and geometric parameters of pillars.
- Various forms and geometric parameters of rooms.
- Various conditions of the extracted area after finishing their exploitation.
- Various sequence in extraction of the room mine stores.

The variety of applied versions of the open stope and pillar exploitation system, has resulted in certain kinds of pillars, divided according to the form and geometric size, which are to be found in the mine as follows:

- Square pillars, with dimensions of 48x48 m;
- Square pillars, with dimensions of 20x20 m;
- Rectangular pillars, with dimensions of 20-30 m;
- Rectangular pillars, with dimensions of 19-27 m;
- Continuos pillars, with length 110 - 120 m, width 16 - 18 m;
- Continuos comb-shaped pillars, with length 110 - 120 m, width 18 - 19 m and narrowing - 6 m;
- Continuos comb-shaped pillars, with length 110 - 120 m, width 18 - 20 m and narrowing – 12 m;
- Barrier pillars with dimensions 120 -120 m.

According to the condition of the extracted area after finishing the exploitation, the rooms in the mine plant are known to be with filling and without filling.

Parameters of the open stope and pillar upon gypsum exploitation
Table № 1

Mine field	Depth of Bedding	Thickness of layer	Angle of dipping	Length Of Room	Width Of Room	Thick-ness Of safety bench	Pillar dimensions	Extract ratio
	m	m	°	m	m	m	m	η
Koshava Bulgaria	297	30	18	12	7	3	15-17	0,36-0,40
Shoals- USA	105-158	30	6	3,6-5,2	7,5-9	-	6 x 9	-
Stemp Hil-England	30-270	24,4-36,6	6	9,14	4,88	-	7,2 x 7,2 6,4 x 12	0,5-0,75
Britling-England	40	2,1-6	-	1,8-4,8	6,4	-	6,4 x 6,4	0,56-0,79
Taverni-France	45-80	9-12	0	7,5-9,5	8	2	16 x 16 4 x 4	0,40-0,65
Port-Maron-France	70-80	8	1	6	7,5	2	6,5 x 6,5	0,70
Gorazobaerk -Ukraine	150	10-16	5-8	9-14	8	0	5 x 150	0,61
Olekminsk-Russia	35-65	6-11	8-10	6-7	10	1-2	6 x 100	0,42-0,46
Beblovska-Russia	90	4,4	0-3	3-4	8	1	4 x 10	0,38-0,40
Artemovska-Russia	100	25	3-7	15-18	8-11	5,5	12 x 30 12 x 100	0,32-0,42
Neomoskovska-Russia	120-130	17	0-2	9-11	10-11	6,5-8,5	9 x 50 10 x 50	0,34-0,36
Kamsko Ustinskaja-Russia	100-130	12	0-1	10-12	15	0	12 x 20	0,62-0,70
Dambo Main-Canada	116	1,5-2,4	5	-	6	-	6 x 6	-
Obrigeim Germany	-	12-13	2	11,5-12,5	10	-	8 x 15	0,74

To be in position to follow easier the analysis of the geometric forms of pillars, an experimental task to divide the mine plant in districts has been undertaken. Consequently 3 districts have been established which on turn according to secondary attributes have been subdivided in few districts. There are 2 main factors which are known to be taken into consideration upon split of the mine: creeps through out the years, and the appropriate version of the applied open stope and pillar (with or without backfilling).

Analysis of the geometric parameters of pillars in the area of creeps fields (district 1)

The district is situated in the northeast part of the mined area. Three creeps have been registered in it as follows:

- In 1976 sudden caving of rectangular pillars have appeared, (1A);
- In 1991, in the district of bore – hole № 24 arised a self – caving, known as chimney-like heading which has reached the surface (1B);
- In 1992 a mass creep of square pillars in the district of drift № 14 has come up, (1C);
- On 05.03.1992 has been registered a creep in the extraction area of the district known as "Bermudian triangle" (in the north part of the mine field). The creep arised along with self - caving known as chimney-like heading. To prevent from further development of that chimney - like heading to the surface, certain walls of reinforced concrete have been built and a partial backfilling with dry sand has been made in the extracted areas, (1D).

Moulds of subsidence spread out wide and deeply in the area are believed to be the result from the creep at the surface. It is necessary to stress on the fact that waters from quaterner water-carrying horizont did not penetrate in the mine -field. The land did not become boggy and the soil productivity has been preserved. There will be no more extraction works in the district and it should be liquidated by backfilling the not caved existing rooms left under the village of Koshava. The observations for assessment of the surface conditions in "Koshava" mine should go one. The necessity to study the deformation processes has a principal importance for assuring a trouble free development of the mine works as long as the mine exist.

District 1A

It is situated to the north of the main extract haulage drift 3. The working parameters are given in table 2.

Basic geometric parameters of district 1A
Table 2

PARAMETERS	VALUE
Thickness of gypsum seam	18,6 m
Depth of mine works	263 m
Specific weight of gypsum	0,0223 MN / m³
Width of pillars	16 m; 18 m
Height of pillars	14 m
Width of rooms	7 m
Height of rooms	14 m
Length of rooms	200 – 240 m

The ratio of width toward height $R = W_p / h_p$ for the specified dimensions is as follows:

$$R = 16 / 14 = 1,14$$
$$R = 18 / 12 = 1,5$$

District 1B

It is situated round a bore – hole № 24 and rooms № 55, 56, 1/14, 1'/14, 1"/14. Rectangular pillars of dimensions 20 x 31 m and 19 x 27 m are available.

Basic geometric parameters of district 1B
Table 3

PARAMETERS	VALUE
Thickness of gypsum seam	19,6 m
Depth of mine works	260 m
Specific weight of gypsum	0,0223 MN / m³
Width of pillars	19 m; 20 m
Height of pillars	15 m
Width of rooms	7 m
Height of rooms	15 m
Length of rooms	20 m

The ratio of width toward height $R = W_p / h_p$ for the specified dimensions is as follows:

$$R = 19 / 15 = 1,27$$
$$R = 20 / 15 = 1,33$$

District 1C

It is situated round a bore – hole № 14. Square pillars of dimensions 20 x 20 m are predominated.

Basic geometric parameters of district 1C
Table 4

PARAMETERS	VALUE
Thickness of gypsum seam	19,6 m
Depth of mine works	260 m
Specific weight of gypsum	0,0223 MN / m³
Width of pillars	18 m; 22 m; 24 m
Height of pillars	15 m
Width of rooms	7 m
Height of rooms	15 m
Length of rooms	18 m; 20 m; 30 m

The ratio of width toward height $R = W_p / h_p$ for the specified dimensions is as follows:

$$R = 18 / 15 = 1,2$$
$$R = 22 / 15 = 1,47$$
$$R = 24 / 15 = 1,6$$

District 1D

It is situated in the middle part to the north of a panel drift 3.The registered creep of the extracted area is going along with a self-caving structure, known as chimney-like heading. To prevent from further development of that chimney-like heading to the surface, certain walls of reinforced concrete have been built in the extraction rooms in the area of creep and a partial backfilling with dry sand has been made.
There will be no more extraction works in the district and the remaining part of the mine stores should be registered as items out of the balance sheet.

Basic geometric parameters of district 1D
Table 5

PARAMETERS	VALUE
Thickness of gypsum seam	19,6 m
Depth of mine works	210 m
Specific weight of gypsum	0,0221 MN / m³
Width of pillars	18 m; 20 m
Height of pillars	13 m
Width of rooms	6 m
Height of rooms	13 m
Length of rooms	20 m

The ratio of width toward height R =W_p / h_p for the specified dimensions is as follows:

R = 18 / 13 = 1,38
R = 20 / 13 = 1,53

Analysis of the geometric parameters of pillar in the open stope and pillar without backfilling the rooms (district 2)

The district comprises the central part of the mine plant. In the west and in the north the district borders coincide with the natural borders of the mine field. The outlines of the safety pillar placed under the rail - way and the pillar of the industrial site serve as borders in the south and in the east. Most of the old exploitation fields, which have been exploited before 1973, are also supposed to get into the district. Those fields have been purposely insulated by forced caving of the panel drifts, assuring the access to them, because of danger of sudden collapse of pillars. The condition of rooms inside both fields is not known, but it is quite probable that some amount of accumulated waters might be available. The complicated geo-mechanical conditions are attributed by the availability of some self-caving structures, known as chimney-like headings. To prevent from further development of those chimney-like headings in the works, certain protective barriers of reinforced concrete have been built and backed up by dry sand. Extraction works are known to have taken place within 1976-1980. A open stope and pillar of exploitation with rib pillars without further room backfilling has been applied. The basic parameters of the system are given in table № 6.

Basic geometric parameters of district 2
Table 6

PARAMETERS	VALUE
Thickness of gypsum seam	19,6 m
Depth of mine works	230 – 260 m
Specific weight of gypsum	0,0225 MN / m^3
Width of pillars	16 m; 17 m; 19 m
Height of pillars	11 – 12 m
Width of rooms	7 m
Height of rooms	11 – 12 m
Length of rooms	102 - 128 m

The ratio of width toward height R =W_p / h_p for the specified dimensions is as follows:

R = 16 / 11 = 1,45
R = 17 / 11 = 1,55
R = 19 / 11 = 1,73

Analysis of the geometric parameters of pillar in the open stope and pillar with a follow up backfilling the rooms (district 3)

The district is located in the central part of the mine plant. The extraction works in the district are carried out by partial- or entire- backfilling of the extracted rooms. Some old extracted rooms are to be found in the district. For that reason it is necessary to backfill them as an indispensable condition for extraction of the mine stores left, du to the fact they have been locked in rib pillar room fender.

The parameters referring as to the version of backfilling, is shown in table № 7.

Basic geometric parameters of district 3
Table 7

PARAMETERS	VALUE
Thickness of gypsum seam	19,6 m
Depth of mine works	290 – 330 m
Specific weight of gypsum	0,0225MN / m^3
Width of pillars	16 m; 17 m
Height of pillars	12 - 13 m
Width of rooms	5 – 8 m
Height of rooms	12 – 13 m
Length of rooms	110 - 132 m

The ratio of width toward height R =W_p / h_p for the specified dimensions as follows:

R = 16 / 12 = 1,33
R = 17 / 12 = 1,42

Going through the above analysis on the pillar works, following results are supposed to be concluded: the pillar strength is closely related to the volume and the geometric form. The reached correlation R vary in the range of 1,14 - 1,73. The comparison made in the present study has demonstrated that the version with long rib pillars in the open stope and pillar without backfilling has substantial advantages which can be categorized as bigger stability of the supporting pillars. The general results from the comparative analysis are specified in table № 8

Results from the comparative analisis
Table 8

DISTRICT	R	S_0, MPa	% of the total pillar quantity in the district
1A	1,14 – 1,15	17,5	66
1B	1,27 – 1,33	17	83,3
1C	1,2 – 1,47 – 1,6	12,5	60,5
1D	1,38 – 1,53	16,3	75
2	1,45 – 1,55 – 1,73	16,5	47
3	1,33 - 1,42	16,2	91

CONCLUSION

It turned out to be quite complicated issue to draw analysis on the geometric parameters of the pillars in Koshava mine field, having in mind the great variety of forms and dimensions of pillars and the applied versions of the open stope and pillar system of exploitation. The collapse processes which are to be found in different part of the mine demonstrate that one of the main problems to be solved is the estimation of the stability of the pillars and rooms which are varied in types, geometric forms, location and sequence of building.

A second possible source to become more representative could be the pillar strength, defined in a empiric way, as well as the safety ratio, provided that they have been included in the terms of the problem.

Thus there are appropriate replies to the questions of substantial importance for the further development of the mine works in mine plant and they could be found.

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