DETERMINATION OF OPTIMAL CONTOURS OF OPEN PIT MINE DURING OIL SHALE EXPLOITATION, BY MINEX 5.2.3. PROGRAM

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ABSTRACT By examination and determination of optimal solution of technological processes of exploitation and oil shale processing from Aleksinac site and with adopted technical solution and exploitation of oil shale, derived a technical solution that optimize contour of the newly defined open pit mine.

In the world, this problem is solved by using a computer program that has become the established standard for quick and efficient solution for this problem. One of the computer's program, which can be used for determination of the optimal contours of open pit mines is *Minex 5.2.3.* program, produced in Australia in the Surpac Minex Group Pty Ltd Company, which is applied at the Mining and Metallurgy Institute Bor (no. of licenses are SSI - 24765 and SSI - 24766).
In this study, authors performed 11 optimization of deposit geo - models in Minex 5.2.3. based on the tests results, performed in a laboratory for soil mechanics of Mining and Metallurgy Institute, Bor, on samples from the site of Aleksinac deposits.
Keywords: Oil shale, sample testing, the Minex 5.2.3. program, the optimal open pit

Introduction

Determining the optimal contour of open pit mine is a necessary step in open pit mine exploitation. The main characteristic of this design phase is complexity and large number of possible solutions that meet technical – technological conditions, but with differences, according to economic effect. Therefore, it is necessary to undergo various solutions to techno - economic analysis of individual variants and adopt a solution that will be optimal for the given conditions [1, 6, 9].

This task can be solved by different methods, using classical techno - economic analysis or using modern techniques of mathematical programming. Techno - Economic Analysis is performed using qualitative and quantitative predictions of all factors and conditions that can provide desired result. Qualitative assessment includes the following indicators: mining - geological and hydro - geological conditions [1], organizational and economic factors [3, 7, 8]. Quantitative assessments include: funds use for a certain period of time, dynamics of investments, costs tones of products, effects, use of legislative materials and so on.

Methods of linear and dynamic programming are applied for solving problems with a large number of variants and possible solutions. To solve this task, there are several computer programs for data processing and model setup. Application of mathematical models can be established if there is a certain analogies and similarities between the mathematical formula and the actual work processes to be modeled.

Description of MINEX 5.2.3 program

The development of computer technology, and due to information revolution in the mid eighties of the twentieth century, appeared the first software packages specialized in areas of geology and mining. Today, these programs have evolved into extremely powerful and useful tool aimed at reducing time needed to produce geo-model of studied deposits and open pit mines, saving money and creating detailed 3D model of ore bodies and mines. One of these programs is *Minex 5.2.3* which is a specialized program for 3D modeling, exclusively for layered deposits, especially coal deposits.

With this software it is possible to develop a geological model of layered deposits, to model faults, determine the optimal contour of open pit mines, construct a detailed appearance of open pit and tailing dumps, determine dynamics of excavation and disposal of tailings.

Starting point for work in this program is: situational map in digital format (topography for new mines or initial state of works on the open pits, usually in AutoCAD format) and data from exploratory drill holes about their spatial position, lithology and quality parameters in Excel format [1, 2, 3, 4, 6, 11]. Geo-model of the deposit is created based on data from the drill holes. Each layer in geo - model has its own grid (area represented by a network of certain dimension) of roof, floor and thickness of the deposit, as well as grid of quality for each observed component. Geo - model is produced by following tools:

- *Borehole DB* – Forming a base of boreholes for geological modeling
- *Statistical analysis* - Analysis of the regularities of components distribution in the deposit
- *Seam model* – Layers modeling and calculation of geological reserves

When the geo - model is created and initial state of terrain is put in, optimization is performing, i.e. determination of the optimal contour of open pit mine according to technical - economic parameters of exploitation. The resulting optimal contour is a guideline for detailed construction of open pit mine. This phase of design is done by *Pit Optimizer* tool.

In *Minex 5.2.3* program, it is possible to construct a detailed layout of the final look of open pit mine and waste rock dumps with transport routes and top and bottom edges of each floor, as well as creating excavation dynamic by *Pit design* tool.

Also, with this program, it is possible to make full mining - geological graphic documentation.

Geo – model of deposit

Geo – model of oil shale deposit is made based on earlier data [1] and samples from the site, tested in the Mining and Metallurgy Institute Bor [6]. Following parameters have been systemized:

- Spatial position - X, Y and Z coordinates of a borehole's mouth, the length of borehole pillar, azimuth and strike direction; deviation of borehole pillar;
- Lithology per borehole pillar:
- Content of important parameters (quality) per borehole pillar - oil content (*ulj* in the model) water content (*H_2O* in the model); content of coke (*pk* in the model); gas component with losses (*gg* in the model).

On location of Aleksinac oil shale deposits are defined two basic layers, S1 and S2 (roof and floor oil shale layers, between which are layers of coal and overburden), but the S1 layer is divided into two parts, S1a and S1b, because, inside layer S1 are overburden inter-layers of significant thickness. The amount of overburden above the layers, the amount of oil shale in layers and quality parameters are shown in Table 1. 3D model of oil shale layers in Minex 5.2.3 program is shown in Figure 1.

Table 1. *Quantities and quality of Aleksinac oil shale deposit*

UPPER SURFACE: Topo.grd; LOWER SURFACE: S2SF.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Tonnage	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	458 714 392	688 071 588	91 726 433	190 607 527	2,41	12,31	5,17	76,65	6,03
S1b	12 412 541	18 618 812	70 142 786	145 756 710	0,09	7,32	3,38	82,54	6,76
S2	73 220 337	109 830 506	53 765 704	111 725 133	0,66	11,59	5,88	76,66	5,58
TOTAL	544 347 270	816 520 905	215 634 923	448 089 370	1,21	10,51	4,76	78,57	6,15

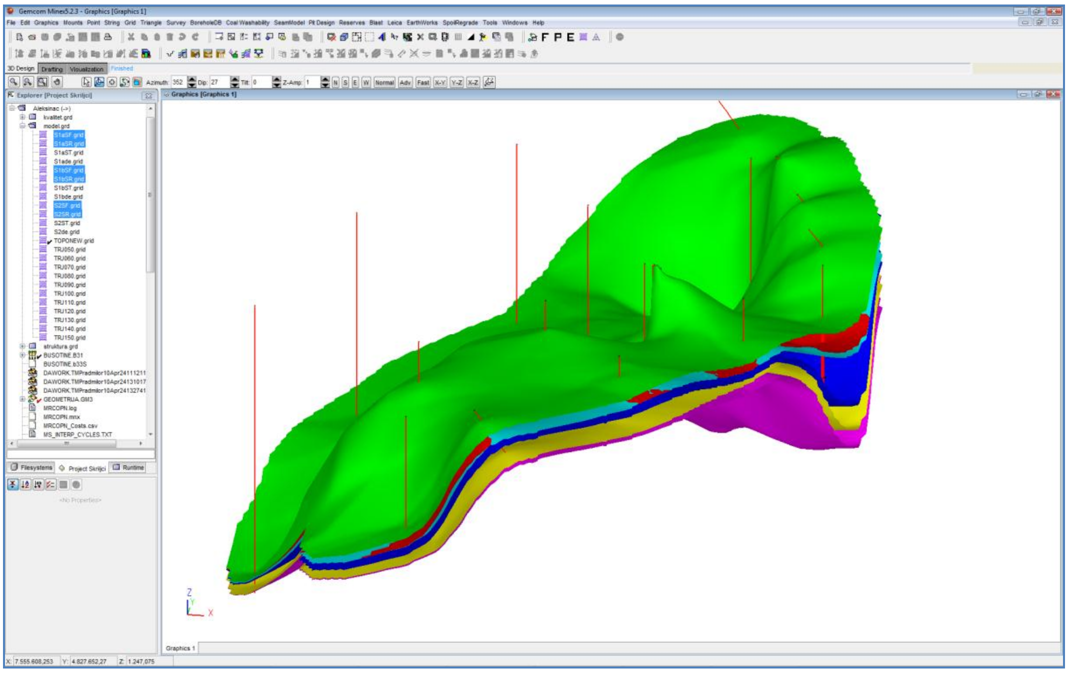

Figure 1. *3D model of oil shale layers in Minex 5.2.3 program*

Selection of optimization input parameters

Optimization of open pit mine in *Minex 5.2.3,* i.e. in his tool *Pit Design,* is done with *Pit Optimizer* option, which is based on *Lerches and Grossman* algorithm. *Lerches and Grossman* algorithm is a procedure for determining optimal mining as one with the highest value for the corresponding set of costs and recovery factors.

Input parameters for the *Pit Optimizer* are:

1. Economic parameters:

1.1. Selling price of oil

1.2. Costs of tailings excavation

1.3. Costs of oil shale excavation

1.4. Costs increasing caused by increasing depth of open pit mine

1.5. Costs of oil shale processing

1.6. Initial and final discount factor and discount factor step

2. Technical parameters:

2.1. Initial state of the terrain

2.2. Geo – model of the deposit

2.3. Bulk density of oil shale

2.4. Final pit slope angle

2.5. Minimum distance between floors in progress

2.6. Utilization of the exploitation

2.7. Utilization of processing oil shale

Selling price of oil has been adopted by current market conditions to 85 $ for barrel. Reduced to medium oil content in oil shale for the whole deposit, a value of 1% of oil is $ 2,57.

Costs of tailings and oil shale excavation for optimization [1, 6, 9, 12] were adopted based on experience from open pit mines with similar conditions and they are $ 5.00 / m3 of excavated overburden and 2,50 $ / t of excavated oil shale. Costs increasing, with increasing depth of the open pit, was adopted, based on experience with open pit mines with similar conditions, and it is 0,01 $ / m

Costs of oil shale processing [9, 12] include preparation of oil shale (shredding and separation from sterile and carbon components) and pyrolysis process. These costs, according to previous researches, are $ 12,00 / t.

Discount factor is varied in the range of 0,5 to 1,5 of the selling price of oil, with step of 0,1.

Oil shale bulk density is previously defined [1, 6]. The mean value of dry density of oil shale, according to this document, is 2,078 t/m^3.

Final angle of the open pit slope [5, 10, 12], depending on its depth, is defined in [12] as the mean value of the final angle of the open pit, that will be used for optimization. Adopted value for an angle is 30°.

Minimum distance between floors, during progress of mining activities, is determined depending on the equipment used in the exploitation. Adopted distance is 20 m.

Utilization on the open pit mine [9, 10, 12] was adopted based on experience with open pit mines with similar conditions, and it is 90%.

Utilization of the fragmentation and separation [9, 10, 11, 12] of sterile and carbon components is estimated at 75%. Utilization of the pyrolysis is estimated at 85% on oil yield.

These data were put into the *Pit Optimizer*, which is shown in Figure 2.

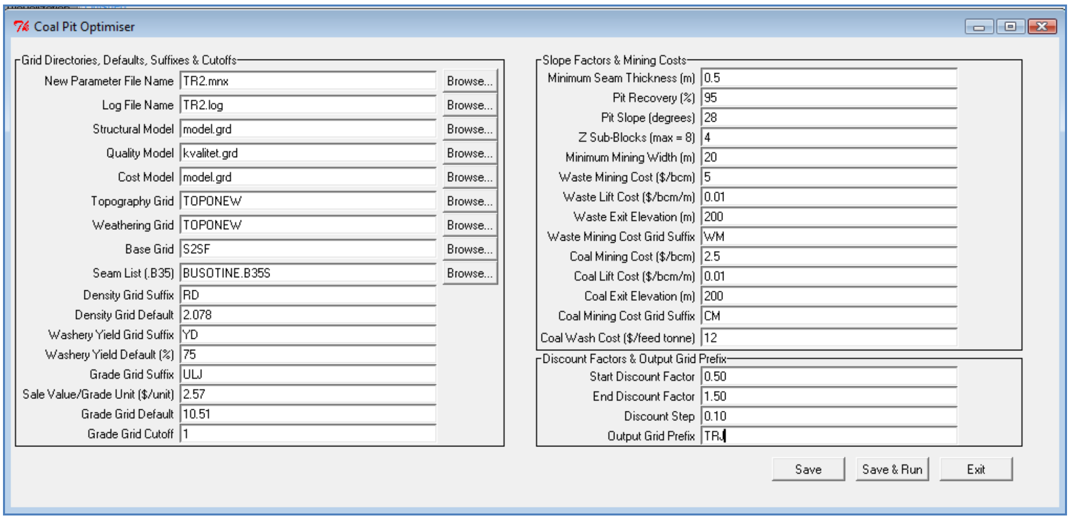

Figure 2. *Input parameters for Pit Optimizer in Minex 5.2.3 program*

Results of optimization

Eleven cases of optimal contour of open pit mine were analyzed by optimization, with varying of oil selling price discount factor ± 50% of market value, in steps of 10%. Optimization results are shown in Tables 2 to 12. Values of the open pit mines obtained by optimization are given in Table 13.

Table 2. *Quantities and quality for open pit mine 1 with discount factor of 0,5*

PIT NAME: TRJ0050.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0050.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	14 675	22 013	295 566	614 187	0,02	12,12	5,28	75,88	6,69
S1b	0	0	0	0	0,00	0,00	0,00	0,00	0,00
S2	0	0	0	0	0,00	0,00	0,00	0,00	0,00
TOTAL	14 675	22 013	295 566	614 187	0,02	12,12	5,28	75,88	6,69

Table 3. *Quantities and quality for open pit mine 2 with discount factor of 0,6*

PIT NAME: TRJ0060.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0060.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	7 601 784	11 402 676	9 666 036	20 086 022	0,38	12,11	5,10	77,03	5,76
S1b	104 577	156 866	269 151	559 296	0,19	7,03	3,35	83,08	6,56
S2	0	0	0	0	0,00	0,00	0,00	0,00	0,00
TOTAL	7 706 361	11 559 542	9 935 187	20 645 318	0,37	11,97	5,06	77,19	5,78

Table 4. *Quantities and quality for open pit mine 3 with discount factor of 0,7*

PIT NAME: TRJ0070.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0070.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	14 030 684	21 046 026	14 181 280	29 468 699	0,48	11,87	5,03	77,39	5,72
S1b	228 677	343 016	1 039 801	2 160 707	0,11	7,46	3,64	82,11	6,80
S2	19 307	28 961	0	0	0,00	0,00	0,00	0,00	0,00
TOTAL	14 278 668	21 418 002	15 221 081	31 629 406	0,45	11,57	4,93	77,71	5,79

Table 5. *Quantities and quality for open pit mine 4 with discount factor of 0,8*

PIT NAME: TRJ0080.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0080.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	23 059 402	34 589 103	18 062 744	37 534 383	0,61	11,85	5,00	77,49	5,67
S1b	543 918	815 877	4 908 800	10 200 486	0,05	7,35	3,51	82,51	6,64
S2	1 228 803	1 843 205	73 795	153 346	8,01	16,42	8,13	69,72	5,72
TOTAL	24 832 123	37 248 185	23 045 339	47 888 215	0,52	10,91	4,70	78,53	5,88

Table 6. *Quantities and quality for open pit mine 5 with discount factor of 0,9*

PIT NAME: TRJ0090.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0090.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	34 505 887	51 758 831	20 688 573	42 990 855	0,80	11,97	5,05	77,30	5,74
S1b	726 930	1 090 395	7 226 016	15 015 661	0,05	7,31	3,49	82,58	6,63
S2	7 234 006	10 851 009	1 840 925	3 825 443	1,89	12,99	7,02	74,99	5,00
TOTAL	42 466 823	63 700 235	29 755 514	61 831 959	0,69	10,90	4,79	78,44	5,91

Table 7. *Quantities and quality for open pit mine 6 with discount factor of 1,0*

PIT NAME: TRJ0100.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0100.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	46 550 765	69 826 148	23 031 712	47 859 898	0,97	12,00	5,05	77,29	5,71
S1b	935 102	1 402 653	8 375 012	17 403 275	0,05	7,32	3,48	82,59	6,62
S2	9 104 509	13 656 764	2 970 218	6 172 114	1,48	12,78	6,88	75,23	5,10
TOTAL	56 590 376	84 885 564	34 376 943	71 435 287	0,79	10,93	4,82	78,40	5,88

Table 8. *Quantities and quality for open pit mine 7 with discount factor of 1,1*

PIT NAME: TRJ0110.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0110.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	52 142 384	78 213 576	23 936 602	49 740 258	1,05	12,02	5,05	77,27	5,71
S1b	1 045 077	1 567 616	8 915 357	18 526 111	0,06	7,36	3,48	82,55	6,60
S2	10 083 711	15 125 567	3 871 409	8 044 787	1,25	12,72	6,82	75,28	5,15
TOTAL	63 271 172	94 906 758	36 723 367	76 311 156	0,83	10,97	4,86	78,34	5,87

Table 9. *Quantities and quality for open pit mine 8 with discount factor of 1,2*

PIT NAME: TRJ0120.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0120.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	54 947 053	82 420 580	24 325 325	50 548 025	1,09	12,02	5,05	77,28	5,70
S1b	1 084 609	1 626 914	9 225 289	19 170 150	0,06	7,39	3,49	82,51	6,60
S2	10 554 901	15 832 352	4 200 550	8 728 743	1,21	12,74	6,83	75,27	5,14
TOTAL	66 586 563	99 879 845	37 751 164	78 446 918	0,85	10,97	4,87	78,34	5,86

Table 10. *Quantities and quality for open pit mine 9 with discount factor of 1,3*

PIT NAME: TRJ0130.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0130.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	58 173 776	87 260 664	24 655 576	51 234 287	1,14	12,03	5,06	77,27	5,70
S1b	1 125 081	1 687 622	9 547 078	19 838 829	0,06	7,44	3,51	82,46	6,59
S2	10 962 963	16 444 445	4 547 052	9 448 774	1,16	12,73	6,81	75,29	5,14
TOTAL	70 261 820	105 392 730	38 749 706	80 521 890	0,87	10,98	4,88	78,31	5,85

Table 11. *Quantities and quality for open pit mine 10 with discount factor of 1,4*

PIT NAME: TRJ0140.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0140.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	69 488 143	104 232 215	25 681 690	53 366 552	1,30	12,06	5,06	77,24	5,69
S1b	1 143 174	1 714 761	10 075 819	20 937 551	0,05	7,41	3,49	82,51	6,58
S2	11 507 914	17 261 871	5 000 209	10 390 435	1,11	12,72	6,82	75,33	5,10
TOTAL	82 139 231	123 208 847	40 757 718	84 694 538	0,97	10,99	4,89	78,31	5,84

Table 12. *Quantities and quality for open pit mine 11 with discount factor of 1,5*

PIT NAME: TRJ0150.grid; UPPER SURFACE: Topo.grd; LOWER SURFACE: TRJ0150.grid									
Seam	Waste		Oil shale		Strip ratio	Assay			
	Volume	Tonnage	Volume	Tonnage		ulj	gg	pk	H2O
	m^3	t	m^3	t	m^3/t	%	%	%	%
S1a	74 890 758	112 336 137	26 423 161	54 907 329	1,36	12,06	5,06	77,26	5,68
S1b	1 212 326	1 818 489	10 216 726	21 230 357	0,06	7,43	3,50	82,49	3,58
S2	11 948 171	17 922 257	5 247 721	10 904 765	1,10	12,69	6,80	75,37	5,10
TOTAL	88 051 255	132 076 883	41 887 609	87 042 451	1,01	11,01	4,90	78,30	5,83

Table 13. *Review of the open pit mines values got by optimization*

Pit	Waste, m3	Oil shale, t	ulj, %	Costs, $	Revenue, $	Profit, $
1	14 675	614 187	12,12	8 979 087	12 534 593	3 555 507
2	7 706 361	20 645 318	11,97	337 888 916	416 123 976	78 235 060
3	14 278 668	31 629 406	11,57	530 019 727	616 213 781	86 194 054
4	24 832 123	47 888 215	10,91	818 539 733	879 752 302	61 212 570
5	42 466 823	61 831 959	10,90	1 108 897 521	1 134 871 047	25 973 526
6	56 590 376	71 435 287	10,93	1 318 763 542	1 314 740 278	- 4 023 264
7	63 271 172	76 311 156	10,97	1 422 867 622	1 409 618 764	- 13 248 858
8	66 586 563	78 446 918	10,97	1 470 413 126	1 449 070 534	- 21 342 592
9	70 261 820	80 521 890	10,98	1 518 876 505	1 488 755 271	- 30 121 234
10	82 139 231	84 694 538	10,99	1 638 766 956	1 567 328 778	- 71 438 178
11	88 051 255	87 042 451	11,01	1 702 371 815	1 613 709 823	- 88 661 991

Conclusion

Based on existing and new technical parameters, authors of mentioned technical solutions were determined optimal contour of newly-projected open pit mine that achieves the maximum possible profit and the estimated economic parameters.

Based on a result analysis of election the optimum contour of open pit mine for exploitation of oil shale from Aleksinac deposit, conclusion is that the optimum border for excavation is open pit mine No. 3, which gives maximum profit in relation to other projected contours. Quantities of waste and oil shale with its quality are shown in Table 4.

Optimal contour of the open pit mine for oil shale exploitation from Aleksinac deposits contains 31.629.406 tons of oil shale with 14.278.668 m^3 of waste.

Overburden coefficient for the optimal outline is Kr = 0.45 m^3 / t.
Bottom of the mine is on elevation of +25 m. Maximum depth of the open pit mine is 200 m.

An important factor in using *Minex 5.2.3* is ability of changing and comparing several versions of input parameters of optimization. It is also important that less time is needed to determine the optimal contours, comparing with conventional projecting.

Projecting is much more improved by using this program, in terms of time and quality, due to the possibility of rapid analysis in order to select the best solution. The application of this and similar programs has become a necessity and standard in projecting of open pit mines.

This and other specialized computer programs for the mining industry provides great opportunities in design of open pit mines because, with them, it is possible to solve a series of complex problems in this area quickly and with high-quality.

Gratitude

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