TECHNICAL NOTE

USING 2D LERCHS AND GROSSMANN ALGORITHM TO DESIGN FINAL PIT LIMITS OF SUNGUN COPPER DEPOSIT OF IRAN

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Abstract The Sungun copper deposit is located in about 40km north west of Ahar city in the east Azarbaigan province of Iran. The total geological ore deposit is estimated to be 740 million tons. In this study using all information from exploration and geotechnical studies of the area, final pit limits of Sungun copper deposit is designed by the 2-D Lerchs & Grossmann Algorithm. By this method, from 740 million tons of geological ore reserve, 411 million tons can be mined by open-pit method with overall stripping ratio of 2.14:1. Cut off grade is found to be 0.32% Cu. The average ore grade is found to be 0.665% Cu.

Key Words Open Pit, Final Pit Limits, Lerchs-Grossmann Algorithm, Economic Value

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INTRODUCTION

One of the most important stages of open-pit mine design is to determine the final pit limits. After finding the final pit limits of mine, it is possible to determine the size and location of processing plant, the location of waste dumps, etc. In the past, the final pit limits of mine were mainly designed by hand methods. All hand methods of final pit limits begin with vertical sections [1].

These sections should include the mineral block inventory and surface topography. The pit limits are located on each section so the ore grade along the pit limits line support a stripping ratio corresponding to the break even stripping ratio [2]. Hand method is less accurate and consumes more time, particularly in large ore deposit [3].

Due to the tediousness of the procedure, a number of alternative methods mainly, computer techniques, have been developed. One of this alternative methods is 2-D Lerchs & Grossmann Algorithm [4,5].

This paper presents the determination of final pit limits of Sungun copper deposit of Iran, using the 2-D Lerchs & Grossmann Algorithm. Sungun porphyry copper deposit is located in 40 km north west of city of Ahar in longitudinal between 46Ü43Å to 46Ü44Å and in latitude

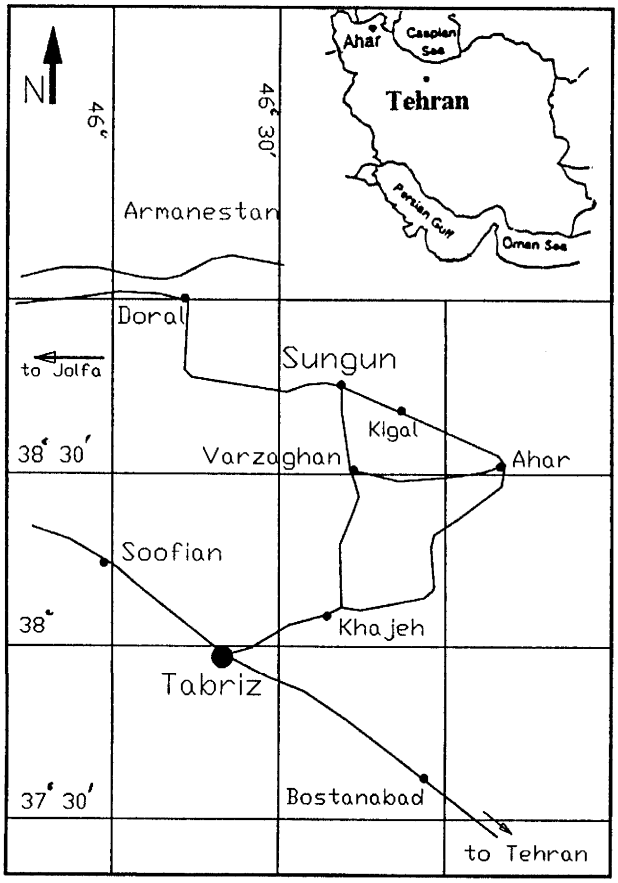

Figure 1. General location of Sungun copper mine of Iran.

between 38Ü40Å to 38Ü43Å (Figure 1).

EXPLORATION HISTORY

Exploration study at Sungun copper deposit started in 1911 and continued up to 1941. At the end of this period the exploration group claimed that Sungun has large deposit of porphyry copper. In 1978 again exploration studies started in Sungun by exploration group of the Sarcheshmeh copper mines of Iran. But a few months later the exploration activity of this group was stopped. In 1989 several exploration experts from geological organization of Iran began to complete previous studies. The results of this new exploration program were: (1) prepareing general map of Sungun in scale of 1: 20000, (2) prepareing geological maps in scale of 1: 5000 and 1:10000, (3) excavating more than 120 exploration boreholes, some of which were in grid of 200 Î 200 m and some in grid of 100 Î 100m, (4) recovering of samples from each borehole with interval of 2m for chemical analysis and (5) performing 5 exploration tunnels with dimensions of 2 Î 2m [6].

MINERALIZATION ZONES

Sungun porphyry copper deposit, like many other porphyry deposits around the world, has three different zones. These are:

(1) The leached zone, the average thickness of which is 80m and copper grade is less than 0.1 percentage. The material of leached zone is considered to be waste.

(2) The supergene zone, the average thickness of which is 100m and contain high grade of copper. The copper grade is ranged between 0.8 to 2 percentage. Most minerals of this zone are chalcopyrite CuFeS), chalcocite (Cu_2S) and covellite (CuS).

(3) The hypogene zone, the average thickness of which is 340m with copper grade ranged between 0.01 to 2 percentage. Most minerals of this zone are chalcopyrite and pyrite with very low percentage of molybdenum.

SLOPE STABILITY

Considering physical and mechanical properties of rock mass, ground water regime and mine area tectonic, the limits of Sungun copper mine are divided into 5 different portions. These portions are north east of mine, north west, central and east, central and west, and south of mine. Table 1 shows the recommended pit slope for 5 portions of mine [7]. The primary geotechnical analysis of mine addressed that circular and toppling failure will not happen, but plane and wedge failure may happen in high pit slope.

CALCULATION PROCEDURE

Number of block Calculation Based on information gathered from all boreholes and

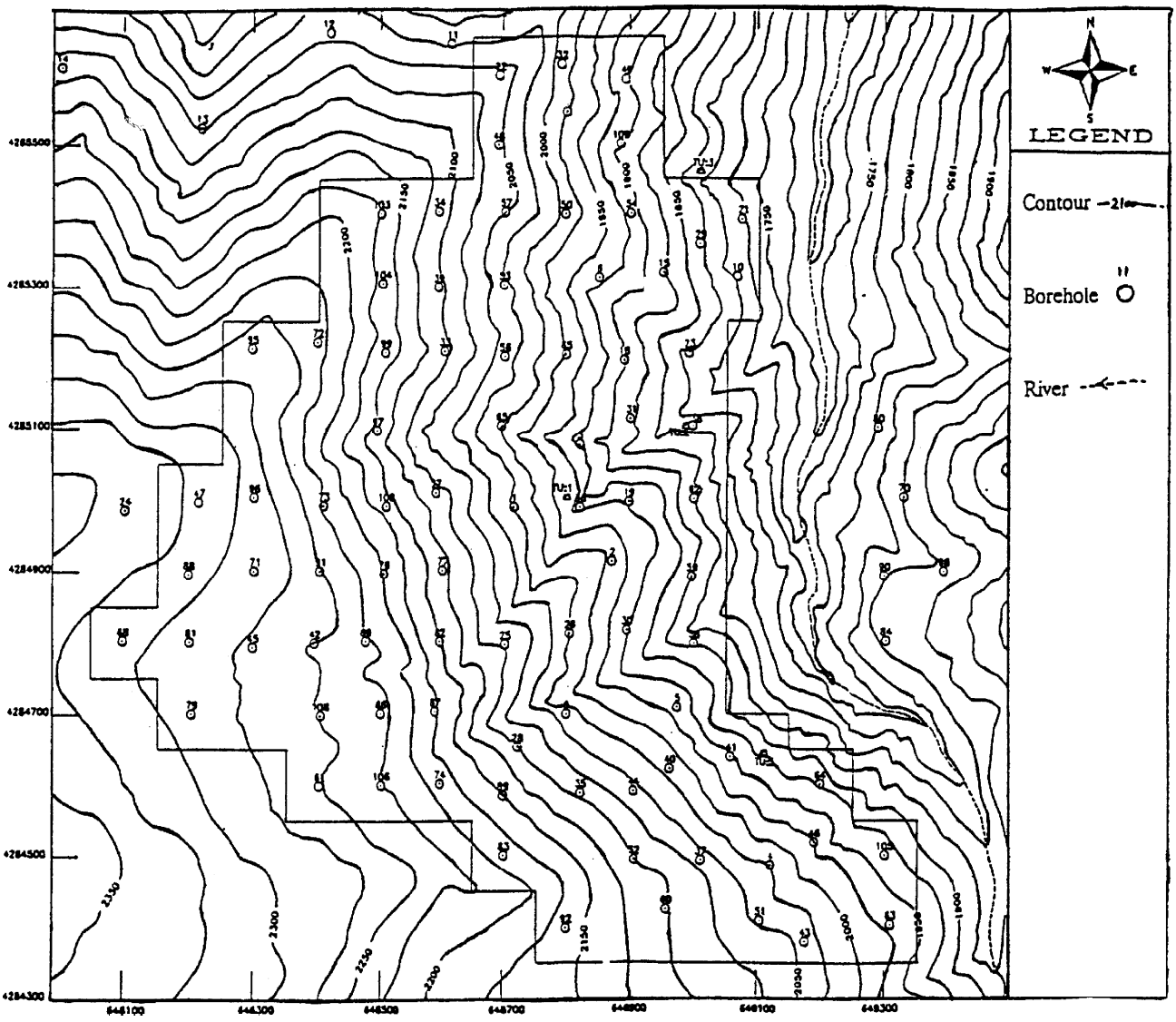

Figure 2. Location of boreholes and exploration tunnels.

TABLE 1. Recommended Pit Slope for Different Portions of Sungun Mine [7].

Portion	recommended slope
northeast	37.5Ü
northwest	37.5Ü
central and east	41.2Ü
central and west	41.2Ü
south	36.5Ü

exploration tunnels, from 647710 up to 649350 on X-axis and from 4284275 up to point 4285675 along y-axis and from level 1600 up to 2370m along Z-axis, have been selected as a large block (1640 x 1400 x 770m).

Based upon the geotechnical study of the Sungun copper deposit, the final pit slope of mine is suggested to be 35Ü and the average specific gravity is evaluated to be 2.5 [7]. With regard to loading system and drilling machine, bench height is selected as 14m. Therefore block width is calculated by the following equation:

$$B = \frac{h_B}{\tan a} \quad (1)$$

where B = block width, h_B = bench height = block height = 14m and a = slope angle.

Substituting the amount of h_B and tan a in formula 1 the block width will be 20m.

The distance between all geological sections was 50m, hence the third dimension of block is selected to be 50m. Therefore, the dimension of each small block will be 14 Î 20 Î 50m and weight of material per block is 35000 tons.

Knowing the size of large block and small blocks, the number of small blocks was found from:

$$N = \frac{1640 * 1400 * 770}{14 * 20 * 50} = 126280 \quad (2)$$

where N = number of small blocks.

Using DATA MINE program and inverse distance weighting technique, the grade of each block is calculated. In the next step, by entering topographic conditions of each section, those group of blocks having more than 50% of their portion above topography level are omitted. By doing so, the total number of small blocks were reduced to 76114 blocks. Table 2 shows the grade and blocks numbers of ore and waste of each section of Sungun copper deposit.

Estimating Economic Value of Each Block

To calculate the economic value of each block, the following equation is used:

$$BEV = TPB \left[\left(\frac{R.g}{G}\right) AMR - (b+c)\right] \quad (3)$$

where BEV = block economic value, TPB = ton per block (35000tons), R = Recovery coefficient (90%), g = average ore grade of each block, G = grade of concentrate (30%), AMR = price of one ton concentrate at mine ($ 405.5 per ton), b = mining cost ($ per ton), c = concentrating cost ($ 2.9 per ton).

Substituting the above values in Equation 3 the block economic value is:

$$BEV = 35000 \left[\left(\frac{0.9g}{30}\right) 405.5 - (1+2.9)\right] \quad (4)$$

where $BEV = 35000 (12.165g - 3.9)$ (5)

Since the blocks have all identical weight, the BEV is divided by 35000, therefore relation 5 is written as:

$$BEV = 12.165g - 3.9 \quad (6)$$

To determine the cut off grade, BEV must be equal to zero, so:

$$g_c = \frac{3.9}{12.165} = 0.32 \quad (7)$$

where g_c = cut off grade.

From 76114 blocks, only 21152 blocks have average grade of more than 0.32%, and thus the total ore reserve is 740,320,000 tons. At this stage block economic value (m_{ij}) of each section is calculated by Equation 6, where i refers to the rows and j to the columns.

To calculate m_{ij} two options were under consideration.

1 - Those blocks having grade less than 0.32% are considered as a waste and their values are minus one dollar.

2 - Those blocks having grade greater than 0.32% are considered as ore and their economic values are calculated.

For example in section 11 in row one and column one and row 20 and column 12 the m_{ij} have been calculated by the following procedure.

$g_{11} = 0.003$

Since $g_{11} = 0.003 < 0.32$ therefore $m_{11} = -1$

For $g_{20\ 12} = 0.508 > 0.32$, using Equation 6, the block economic value of $m_{20\ 12}$ is 2.28 dollar.

This process is continued for blocks of each section. It should be noted here that, section 11 of Sungun copper deposit produces more profit than any other section (Figure 3).

The next step was to calculate the cumulative value for each column of blocks (M_{ij}). At this stage, row 0=0 was added to top row and zero was also added to position (i= 0 ,

TABLE 2. Number of Blocks of Different Grade Range.

Section	Grade range(%)						total	
	0-0.32	0.32-0.5	0.5-0.7	0.7-1	1-1.5	>1.5	ore	waste
1	2306	502	202	96	0	0	800	2306
2	2286	587	291	95	13	2	988	2286
3	2520	292	468	125	20	2	907	2520
4	2532	360	389	146	11	6	912	2532
5	2516	246	399	193	26	10	874	2516
6	1992	308	451	184	40	21	1004	1992
7	2052	230	340	296	24	25	915	2052
8	2388	196	364	293	63	16	932	2388
9	1862	216	226	322	76	24	864	1862
10	998	336	359	349	64	18	1126	998
11	1264	221	269	421	47	8	993	1264
12	1194	427	287	416	22	1	1153	1194
13	1586	231	256	358	38	11	894	1586
14	1490	318	483	216	22	0	1039	1490
15	1840	292	240	163	41	4	740	1840
16	1774	322	239	140	27	0	728	1774
17	1744	353	182	128	34	6	703	1744
18	1694	370	219	92	10	0	691	1694
19	1876	348	218	96	18	1	681	1876
20	1714	420	217	77	6	0	720	1714
21	1534	382	273	107	8	1	771	1534
22	1800	365	190	67	10	8	640	1800
23	2196	161	173	123	31	15	503	2196
24	2236	146	151	110	24	14	445	2236
25	2224	130	161	50	20	46	407	2224
26	2432	83	128	41	11	33	296	2432
27	2586	75	98	21	13	2	209	2586
28	2326	98	83	27	7	2	217	2326
total	54962	8015	7378	4752	726	276	21152	54962

j= 0) in Table M_{ij}. To calculate cumulative value for each column of blocks, beginning from the top and moving downward, the following equation is used.

$$M_{ij} = \sum_{k=0}^{i} m_{kj} \qquad j = 1, 2, 3, \ldots \qquad (8)$$

where M_{ij} is the value calculated in extracting a single column and m_{kj} is the net value of block (kj). Applying Equation 8 to find the value of M_{31} of section 11, we will have:

$$M_{31} = \sum_{k=0}^{3} m_{k1} = m_{01} + m_{11} + m_{21} + m_{31} \qquad (9)$$

where from Table M_{ij} of section 11 :
$m_{11} = m_{21} = m_{31} = -1$ and $m_{01} = 0$. Therefore $M_{31} = -3$.

The third stage was to calculate overall

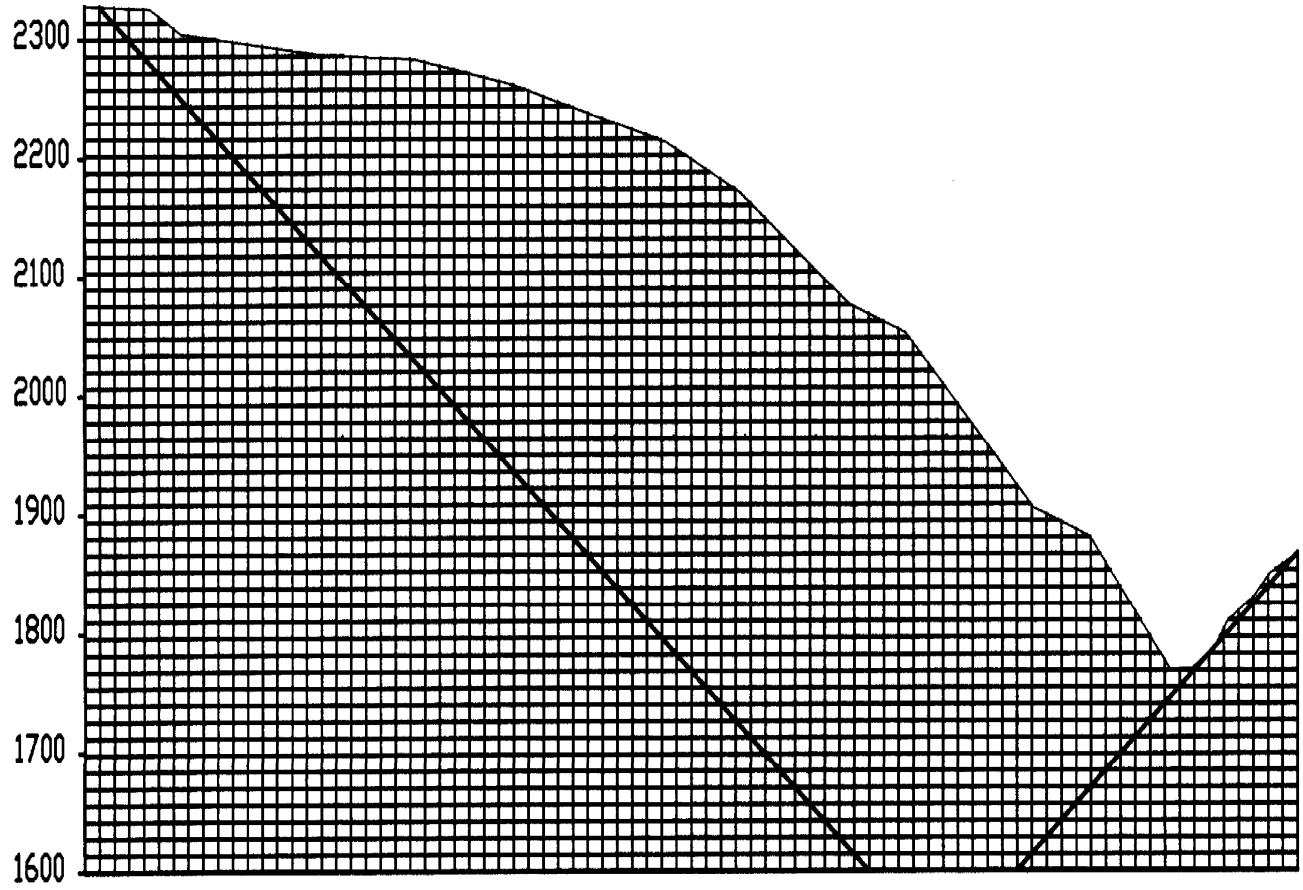

Figure 3. Final pit limits of section 11 of Sungun copper deposit of Iran.

cumulative value of each section. This procedure started from the extreme top left hand of the block to right across the section. To calculate the value of each block (P_{ij}), the following equation is used.

$$P_{ij} = M_{ij} + \max \begin{bmatrix} P_{i-1,\,j-1} \\ P_{i,j-1} \\ P_{i+1,\,j-1} \end{bmatrix} \qquad (10)$$

where P_{ij} = cumulative value of each block, $P_{i-1,\,j-1}$ is the value of block directly above and to the left, $P_{i,\,j-1}$ is the value of block on the left and $P_{i+1,\,j-1}$ is the value of block directly below and to the left.

Of the three values, the block whose value is added to the block M_{ij} and yield the most positive sum is selected. An arrow is drown from the original block (P_{ij}) to that block providing the maximum value. The sum is substituted into the original block for the subsequent calculation.

This procedure is continued in the first column of Table P_{ij}, then column 2 from top to down until all blocks of each section are completed. Then by following an arrow from right to left, the pit limits of each section are determined. This process is continued for all 28 sections of Sungun copper deposit. At the final stage, by section hand smoothing, the optimum pit limits are selected. The optimum pit is the one which yields the maximum value. By this method 411 million tons of ore from 740 million tons of Sungun porphyry copper deposit can be mined. Figure 4 shows the final pit plan of

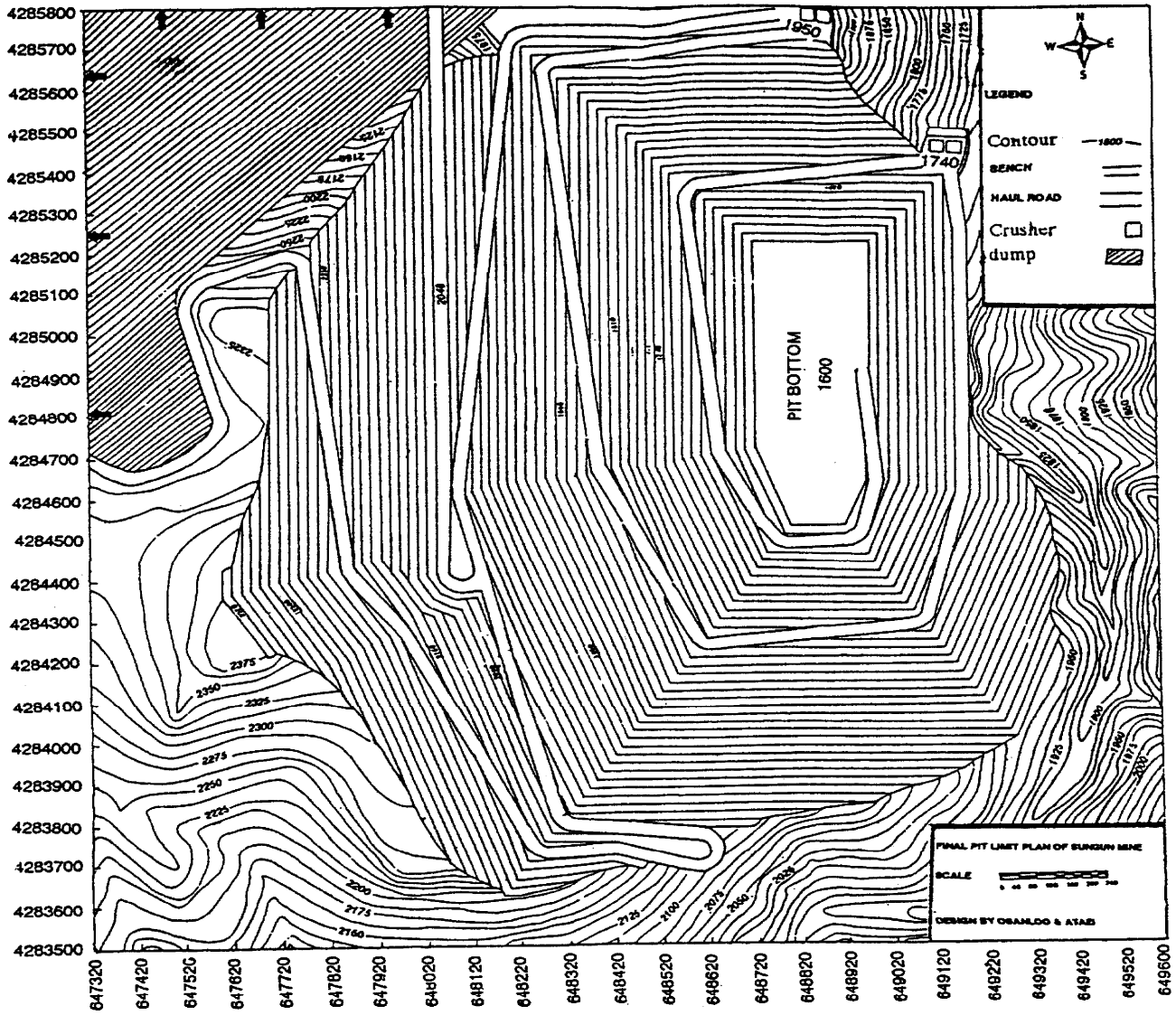

Figure 4. Final pit plan of Sungun copper mine.

Sungun copper mine and Table 3 shows the number of blocks of ore and waste and overall stripping ratio of each section.

MINE ACCESS

Roads are one of the most important aspects of final pit slope designing in open-pit mines. Their presence should be included early in the planning process since the road can have significantly affect on the slope angle and the slope angles chosen have a significant affect on the reserve [4,9]. Their later design can cause a large amount of unplanned waste or the sterilization of some planned reserve [10,11]. On the other hand, most of the currently available computerized pit generating methods do not easily accommodate the inclusion of roads [12]. In this study the addition of a road in plan was under consideration. Based upon the height of the bench and considering road grade to be 8 percent, the length of the road in plan is calculated by the following equation:

$$L = \frac{(N_b * h_B)}{R_g} \qquad (11)$$

TABLE 3. Blocks Number of Ore and Waste and Overall Stripping Ratio of Each Section.

Section	ore	waste	W.O
1	0	0	0
2	520	1003	1.93
3	339	813	2.4
4	422	770	1.82
5	457	932	2.04
6	688	799	1.16
7	681	722	1.06
8	736	691	0.94
9	665	737	1.11
10	924	481	0.53
11	898	489	0.55
12	839	546	0.66
13	692	699	1.01
14	628	675	1.07
15	858	714	1.22
16	628	575	0.92
17	544	583	1.07
18	494	624	1.26
19	492	728	1.48
20	430	757	1.76
21	367	773	2.1
22	362	857	2.36
23	294	431	1.46
24	276	399	1.44
25	241	252	1.045
26	193	268	1.38
27	160	153	0.956
28	118	138	1.169
total	13673	16609	1.214

And the actual length of the road was found from:

$$La = \sqrt{L^2 + (P_D)^2} \quad (12)$$

To calculate the volume of the material contained in the road (must be removed), the following equation is used:

$$V = \frac{1}{2} * \frac{100 * (P_D)^2}{R_g} * Wt \quad (13)$$

TABLE 4. L , La and V in Sungun Copper Mine.

Mine Roads	L(m)	La(m)	V(m^3)
level 1600 to level 1740	1750	1755.6	3675000
level 1740 to level 1950	3365	3371.5	8268750
level 1950 to level 2300	4375	4389	22968750
level 1950 to level 2048	2245	2549	184800
total	12035	12065	35097300

where L = the length of the road in plan, N_b = Number of benches, h_B = bench height = 14m, R_g = road grade = 8%, La = actual length of the road, P_D = Pit depth, Wt = actual width of the road = 30m and V = Volume of material contained in the road or must be removed.

In Sungun copper mine, the pit bottom will be at the level of 1600 m, based upon the pit bottom, two semi-portable crushers are going to be used. In early years of production, crushers will be installed at the level of 1950m and in later years of production, the two crushers are going to move at the level 1740m. Two major dump locations are selected to be at the level of 2300m and in level of 2048m. With regard to geometry of two dump points and locations of crushers the actual length of the roads (La), length of the roads in plan and the volume of material contained in the roads (V) were found by Equations 11, 12, 13 and shown in Table 4.

MINE YEARLY PRODUCTION

The main objective of Sungun porphyry copper mine plan is to produce 280,000 tons concentrate with grade of 30% and recovery coefficient of 90%, yearly ore production of Sungun copper mine is 14 million tons. For mining 14 million tons ore per year 30 million tons waste must be removed.

RESULT

Gathering all information from exploration and

geotechnical studies of Sungun copper deposit and using DATA MINE program, the geological proven reserve of Sungun deposit is found to be 740,320,000 tons. Using the 2-D Lerchs & Grossmann Algorithm, the final pit limits are determined. Based on this method from more than 740 million tons of geological ore reserve, 411 million tons will be mined by open-pit method. For mining 411 million tons ore, 879.5 million tons waste must be removed. Overall stripping ratio is 2.14: 1, and cut off grade is found 0.32% Cu.

CONCLUSION

1. Using the 2-D Lerchs & Grossmann to find final pit limits of Sungun copper deposit, it is shown that 411 million tons ore will be mined instead of 341.39 million tons ore by hand method [6].
2. Using the 2-D Lerchs & Grossmann, 70 million tons more ore will be mined [8].
3. In comparison to the hand method, the 2-D Lerchs & Grossmann is less time consuming.
4. The Sungun copper deposit require more exploration studies in order to define all categories of geological ore reserve. This requires to determine new economic pit limits, the 2-D Lerchs & Grossmann method is faster and a very helpful method to find the new pit limits at shorter time with higher fullness.

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