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SIMULATION AND MODELING OF PILLAR STABILITY AND ANALYSIS OF SAFETY FACTOR

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ABSTRACT

Simulation and modeling is powerful tool to analyze real time data and can be used to analyze different scenarios using appropriate software that may reduce need of infield data collection process and can predict reasonably accurate results. In this paper the real time data of a mine is used to simulate and model the stresses on the pillars and evaluate the pillar strength and safety factor. The material properties assigned to the model are obtained by testing the representative samples taken from the selected locations of the mine. The mine under investigation has 50 ft wide pillars and 50 ft wide rooms under an average overburden of 650 feet. The effect of reduced pillar dimensions and increased roof span on overall stability of mine and extraction ratio is analyzed using LaModel [1] software. The predicted results of the reducing pillar size are analyzed to compares the current mining practices with the optimized room and pillar size to get better extraction ratio without comprising the safety.

INTRODUCTION

Khewra salt mine is located at the foothills of salt range, about 160 km south of Islamabad, the capital of Pakistan. It is the second largest salt mine in the world and is the oldest one in the sub-continent [2].

Salt has been mined on small scale at Khewra since 320 BC but the systematic mining through room and pillar mining method is however started around 1870. This mining method is still in practice in almost all the present day mines located here. The salt being mined from this location belongs to Precambrian formation which is exposed along the southern escarpment of the salt range formation [3]. There are several salt seams with in this formation ranging in thickness from 65 ft to 295 ft covering an underground area of about 110 km^2. Khewra salt mine has estimated salt reserve of 6.687 billion tons with an average production of 325,000 tons per annum [4].

Salt occurs in the form of an irregular dome like structure having a cumulative thickness of 490 ft (150 meters) overlain by marl and alluvium. The salt found here is of good quality and white to pink in color [4].

The mine comprises of 17 stories, with 11 below ground. The salt-mine is 288 meters above sea level and extends around 730 meters inside the mountains from the mine-mouth. The cumulative length of all tunnels is more than 40 km [2]. Mining is being done by multilevel room and pillar mining method. Access to the deposit is provided through two main tunnels and through a number of inclines which connect the working levels with the main tunnels. A typical mining plan of the Khewra salt mine consists of a uniform pattern of 50 ft wide rooms separated by 50 ft wide pillars oriented in North-South direction connected by access tunnels for each level oriented in East-West direction. Normal height of each room and pillar is 25 ft but in some cases the rooms of the adjacent levels have been cut through, resulting in high room and pillars. The conventional drill and blast method is employed for excavation of salt and for the development work.

The ground control, subsidence and the pillar stability in the mining area is not an immediate concern in that area. However this paper presents preliminary studies regarding the safety of existing mining practices and about the safety and economy for the planned mines. This study was under taken to do the preliminary investigation regarding the selection of optimum pillar size and roof span.

The study involves,

- Collection of representative salt and other rock samples from the selected mine sites for the determination of mechanical properties of rocks.
- Testing of theses samples for the determination of mechanical properties in the rock mechanics laboratory of the Mining Engineering Department, University of Engineering and Technology Lahore, Pakistan.
- Stability analysis of selected mine sections through boundary element stress analysis program LaModel.
- Finally the analysis of various room and pillar configurations to optimize the room span and pillar width to increase the extraction ratio without compromising on safety.

EXPERIMENTAL WORK

The stability assessment software LaModel used in this study requires some physical and mechanical properties of the material and some other information regarding depth and mining geometry [5] [6] [7]. The information regarding mining depth and geometry of salt seams was obtained from mining maps and geological reports. The mechanical properties were determined in the rock mechanics laboratory on the representative samples of salt. The following mechanical properties were determined.

- Uniaxial compressive strength
- Poisson's ratio
- Modulus of elasticity
- Tensile strength

STABILITY ANALYSIS USING LAMODEL

For this study, a section of Khewra salt mine was selected. The selected section comprised of two adits running parallel to each other and connected to the main tunnel. The two adits are separated by a series of rooms and pillars. The selected section consists of five pillars across the adits (along East-West direction) separated by crosscuts and a series of ten pillars along the adits (along North-South direction) separated by rooms. The rooms and pillars have a dimension of approximately 50 ft x 100 ft (16m x 31m) and height of pillars is about 25 ft (8m) [3]. The width of adits is 50 ft and that of crosscuts is 20 ft. The other data obtained after laboratory tests is as follows:

E (Modulus of Elasticity) =210000 psi
v (Poisson's ratio) $=0.25$
G (Modulus of Rigidity) = 8000 psi
g (Specific Gravity) = 2.16
C (Uniaxial Compressive Strength) = 4400 psi
T (Tensile Strength) = 400 psi

τ (Shear Strength) = 730 psi
Overburden depth = 625 ft

The selected section has symmetrical conditions along East, West, North & South i.e. there are other series of rooms and pillars along this section in all directions.

RESULTS

Existing conditions

For the existing pillar dimensions i.e. 50ft x 100 ft, LaModel was run and vertical stress distribution was obtained as shown in Figure 1.

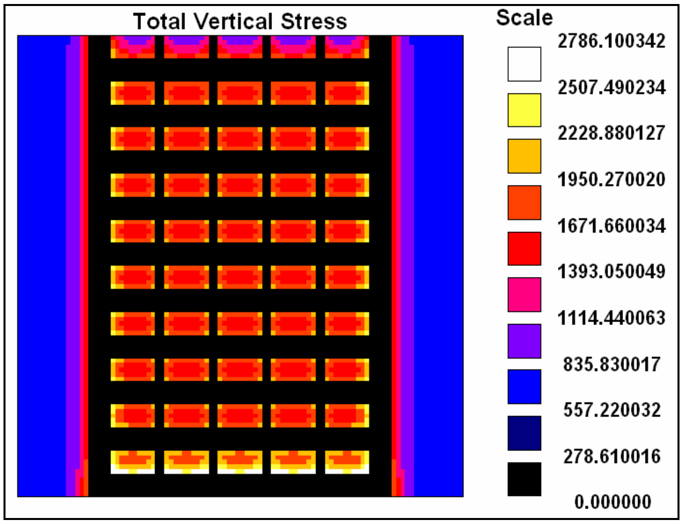

Figure 1. Vertical Stress distribution in Pillars for existing conditions.

The maximum stress concentration is at the corners of the pillars. The safety factor for minimum stress is 16 which is for the roof & floor where as safety factor for the maximum stress at the corner of pillars is 2. The safety factor for the centre of pillars ranges from 2.3 to 2.6 which is generously high. A safety factor 16 to 2 is too high which indicates a possibility of reduction in pillar size resulting in the increase of extraction ratio and production.

Reduced Pillar Size (50 ft x 80 ft)

When the pillar size is reduced to 50 ft x 80 ft, the resulting distribution of vertical stress is shown in Figure 2.

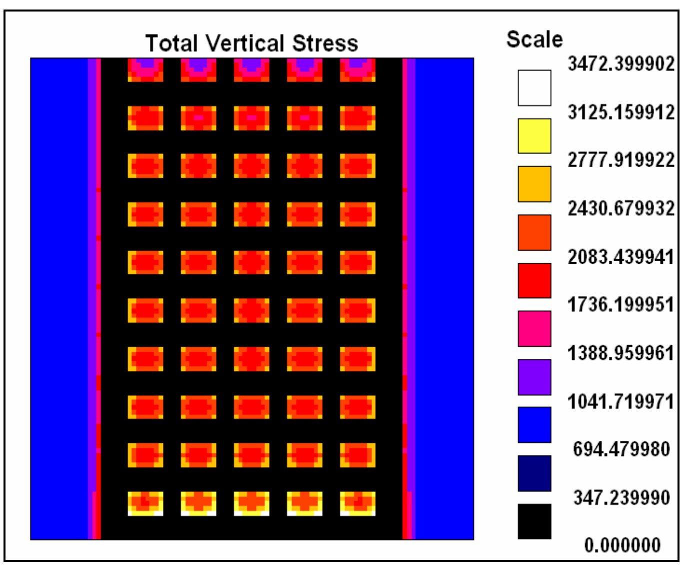

Figure 2. Vertical Stress distribution in 50 ft x 80 ft Pillars.

The safety factor for minimum stress is 13 which is for the roof & floor where as safety factor for the maximum stress at the corner of pillars is 1.6. Safety factor for the centre of pillars ranges from 1.8 to 2.11 which is sufficiently high to withstand the vertical loading. As safety factor is still on higher side, it indicates a possibility of further reduction in pillar size.

Further Reduction of Pillar Size (30 ft x 80 ft)

When the pillar size is further reduced to a dimension of 30 ft x 80 ft, the resulting distribution of vertical stress obtained is shown in Figure 3.

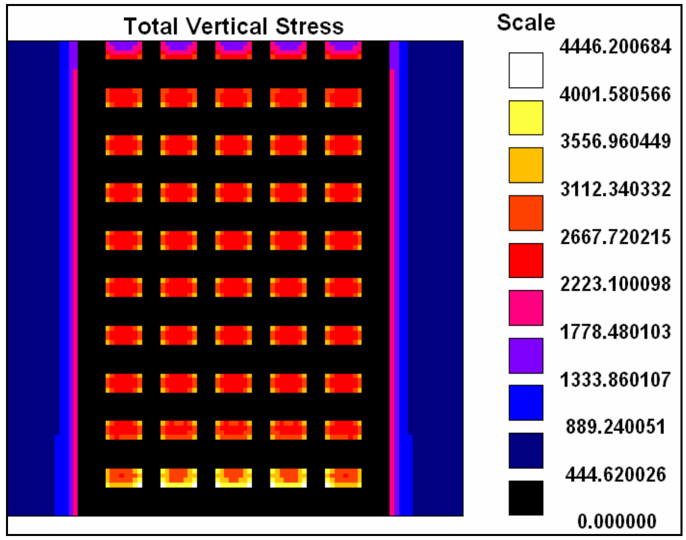

Figure 3. Vertical Stress distribution in 30 ft x 80 ft Pillars.

The safety factor for this pillar dimension is 1.1 at the corners of only a few pillars whereas others have a value of 1.24 at the corners. For the centre of pillars the safety factor ranges from 1.4 to 1.64. This indicates that some crack development may initiate at the corners of some pillars but the centre of pillar is still strong enough to withhold excessive vertical stresses. This means that the pillars can be reduced to a dimension of 30 ft x 80 ft safely without any risk of collapse. The safety factor for roof & floor is still very high-about 9.8 which indicates a strong roof & floor. However further reduction of pillar size may create stability problem which may be observed for a pillar size of 30ft x 70 ft.

Pillar Size (30 ft x 70 ft)

When the pillar size is further reduced to 30ft x 70 ft, the vertical stress was distributed on the pillar as shown in the Figure 4.

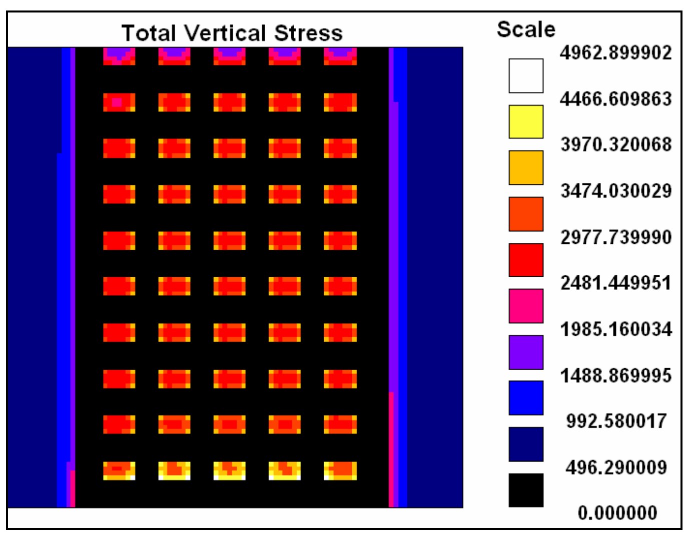

Figure 4. Vertical Stress distribution in 30 ft x 70 ft Pillars.

With this dimension of pillars, the safety factor at the centre was 1.2 to 1.1. This indicates a weak pillar. The safety factor at the corners was 0.98 to 0.88. Thus the pillar will fail at the corners and these corners will fall apart so this dimension is not safe for working.

The results of modeling are summarized in the following table:

Table 1. Different Pillar sizes and safety factor.

Model No.	Pillar Dimensions	Safety Factor			Remarks
		Roof & Floor	Centre of Pillars	Corners of Pillars	
1	50ft x 100 ft (existing)	16	2.3-2.6	2.0-2.1	Excessively high S.F
2	50ft x 80 ft	13	1.8-2.11	1.6	Safe
3	30ft x 80 ft	9.8	1.4-1.64	1.24-1.1	Safe with a few cracks at corners
4	30ft x70 ft	8.1	1.1-1.2	0.88-0.98	Failure at the corners, unsafe

CONCLUSIONS

This study of Khewra Salt Mine using LAMODEL indicates that there is large potential of increased production and reserve utilization by reducing the pillars of the mine. The pillars have excessively large dimensions and large quantities of salt can be recovered by pillar reductions without affecting the safety of mine and operations. The study also indicates that by reducing the size of pillars from 50ft x 100 ft x16ft to 30ft x 80 ft x 16ft, 117,363 metric tons of salt can be recovered from the section understudy, comprising of a series of 5x10 pillars. If only 1000 such sections were reduced, 117.4 million metric ton of salt can be recovered without any risk of failure or safety hazard. The mine consists of many thousands of such section so it is a huge recovery of salt. Although this is still a theoretical study however all the data has been obtained after careful laboratory testing and this model can be tested practically in any section of mine. This modeling can provide the basis for actual mine implementation of this model and optimum resource utilization can be achieved efficiently.

It was found that the present practice of having 50 ft wide pillars and 50 ft wide rooms irrespective of overburden depth and other relevant factors was unnecessarily resulting in low extraction ratio, so it should be revised to optimize the size of pillar and roof span to get better extraction ratio without compromising safety.

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