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Stress Related Fracturing in Dimension Stone Quarries

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Abstract. In Missouri, the horizontal stresses (pressures) in the near surface rock are uncommonly high. While the vertical stresses in rock are simply a function of the weight of the overlying rock, near surface stresses can be many times higher. The near surface horizontal stresses can be in excess of 5 times greater than the vertical stresses. In this research, Flatjack method was used to measure horizontal stress in Red Granite Quarry in Missouri. The flat jack method is an approved method of measuring ground stresses. A saw cut is used to "relax" the stress in the ground by allowing the rock to deform inwards the cut. A hydraulic flat jack is used to inflate the slot; to push the rock back to its stressed position, as measured by a strain gauge on either side of the slot. The pressure in the jack, when the rock is exactly back to its original position, is equal to the ground stress before the saw cut was made. According to the results, present production direction for each pit is not good because the maximum stress direction is perpendicular with production direction. This case causes unintentional breakage results in the loss rock. The results show that production direction should be changed.

1. Introduction

The objectives of this research are to develop a capability of measuring ground stresses in rock, and in the process helping to solve a serious breakage problem for a Missouri quarry.

In Missouri, the horizontal stresses (pressures) in the near surface rock are uncommonly high. While the vertical stresses in rock are simply a function of the weight of the overlying rock, near surface stresses can be many times higher. Figure 1 shows that the near surface horizontal stresses can be in excess of 5 times greater than the vertical stresses. Many engineered structures do not take this into account, and avoidable problems are encountered. Having the capability of measuring ground stresses allows for sound engineering judgment and design.

The Missouri Red Granite Quarry where it is the case study is one of only 3 or 4-dimension stone quarries in Missouri, and the only granite quarry. It produces very hard world class granite, but can have significant losses because of unintended breakage of the stone (Figure 2 and 3). It can be supposed that this occurs because of high horizontal stresses in the rock.

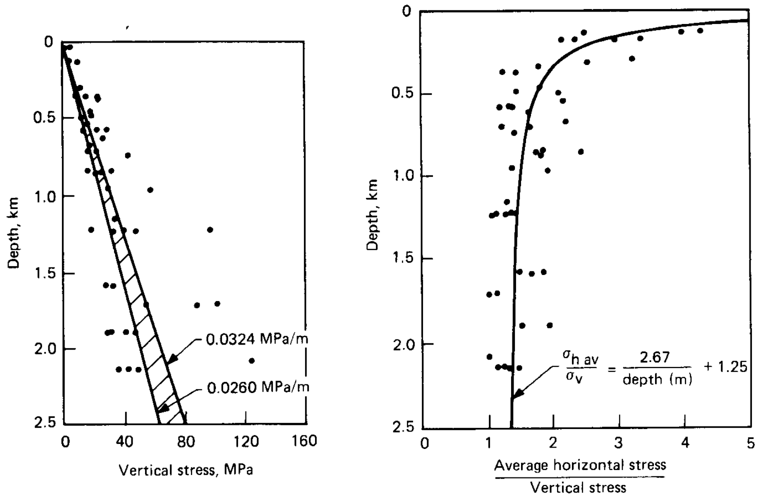

Figure 1. Left: Typical vertical stress profile in the ground. Right: Typical ratio of horizontal to vertical stress, [1]

Figure 2. Unintentional breakage results in the loss rock that could have been cut into large dimension stones, (left): Stress crack in the bottom of the quarry, (right): “Arch” type popup on quarry floor

Figure 3. Unintentional breakage results in the loss of large blocks that have consumed significant resources to extract, (left): Diagonal stress fracture not only ruined the extracted block, but also makes extra work to square off the ledge to begin to extract the next piece, (right): Damaged block; as a result of the curved stress fracture, the block is too short, and is now scrap.

Dimensional stone quarrying today leads to large open pits and underground excavations. However, unlike classical mining operations and excavations for civil purposes [2,3,4] the monitoring and adoption of a consistent design is not yet common practice in dimensional stone quarrying, even when the excavations are very large and irregularly shaped. In this respect, the knowledge of the relative joint orientation, joint strength and basic mechanical schemes of falling or sliding blocks can be suitably exploited to check rock block removal and stability [5,6,7] This knowledge, which is essential for quarry design, should be integrated by monitoring procedures, through the selection of proper devices [8], which provide a direct means of estimating how the exploitation programme can influence the behaviour and stability of the excavated rock structures. The suitability of a mining design or the need for remedial measures for safety improvements can be consistently ascertained on the basis of the measurement and computation of the relevant variables, such as displacements, stress condition and groundwater pressure. The stress condition plays the most important role within them.

Several measuring methods have been applied over the years, however, the present applied techniques are:

- Self-developed and highly improved versions of the originally South African CSIR 2-D Doorstopper
- 3-D CSIR overcoring cells.
- Self-developed hydraulic fracturing
- Flatjack

In this project flatjack method will be used for ground stress. The flatjack or strain nulling method is an approved method of method of measuring ground stresses (ISRM, 1987; Hudson and Harrison, 1997). A saw cut is used to “relax’ the stress in the ground by allowing the rock to deform in toward the cut. A hydraulic flat jack is used to inflate the slot; to push the rock back to its stressed position, as measured by a micrometer across pins on either side of the slot. The pressure in the jack, when the rock is exactly back to its original position, is equal to the ground stress before the sawcut was made.

2. Methods

In Missouri, the horizontal stresses (pressures) in the near surface rock are uncommonly high. While the vertical stresses in rock are simply a function of the weight of the overlying rock, near surface stresses can be many times higher. The near surface horizontal stresses can be in excess of 5 times greater than the vertical stresses. In this research Flatjack method was used to measure of horizontal stress. The flatjack method is an approved method of method of measuring ground stresses [9,10]. A saw cut is used to “relax’ the stress in the ground by allowing the rock to deform in toward the cut. A hydraulic flat jack is used to inflate the slot; to push the rock back to its stressed position, as measured by a strain gauge on either side of the slot. The pressure in the jack, when the rock is exactly back to its original position, is equal to the ground stress before the saw cut was made (Figure 4).

Figure 4. Application of flatjack method in Red Granite Quarry

The 12 cuted slots were made for the stress measurement. While 4 slots were close Open pit-1, 8 slots were close Open-pit-2. All results are tabulated at Table 1. Stress orientations are also shown Figure 5-6. Maximum horizontal stress direction and magnitude can be seen in Figure 7 for each pit.

Table 1. Results of the stress measurements

Number of Cutting Slot	Pit No:	Direction of the Cutting Slot	Magnitude of Stress(PSI)
1	Pit-1	N60E	1320
2	Pit-1	E-W	200
3	Pit-1	N40W	105
4	Pit-1	N-S	50
5	Pit-2	N50E	90
6	Pit-2	N-S	120
7	Pit-2	N80E	110
8	Pit-2	N-S	110
9	Pit-2	N60W	285
10	Pit-2	N30W	150
11	Pit-2	N80E	102
12	Pit-2	N40E	250

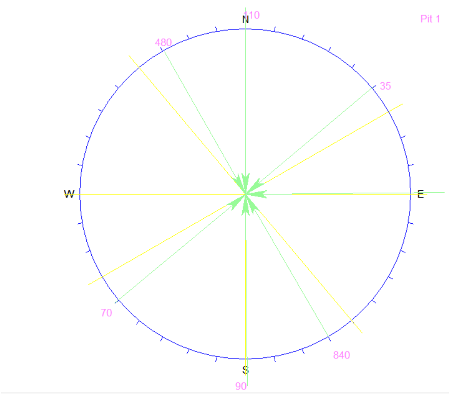

Figure. 5. Magnitude of stress orientations for Open pit-1

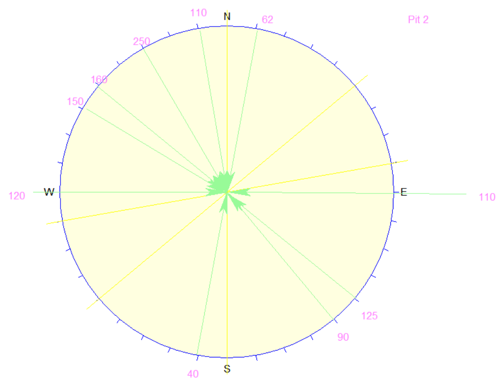

Figure. 6. Magnitude of Stress orientations for Open pit-2

3. Research Results

In this study, joint orientation measurements were carried out in two different regions. The region was named “Open pit-1”, and the other was named “Open pit-2”. 61 field measurements were made, while 181 LIDAR and optical image measurements were made. The lower hemisphere stereographic projection plot of the manually measured orientations in the Open pit-1 showed s the presence of two dominant discontinuity sets; 86/250 and 2/221 One of these sets is nearly vertical and the other is almost horizontal. LIDAR and optical image results are presented as lower hemisphere stereographic projection plot. The LIDAR and optical image results, show three dominant discontinuity sets, with average orientations of 88/247, 3/224 and 86/154. Two sets are almost vertical while one is nearly horizontal. Discontinuity sets were tabulated to compare the two measurement methods. The differences between the numbers of discontinuity sets are due to insufficient manual field measurements. This was because higher parts of the rock face which had a high risk of rock fall, was avoided during the manual field measurements. However, the orientations of discontinuities in the higher areas of the rock face were easily measured from the LiDAR data. This result justifies the usefulness of both LIDAR and optical imaging techniques.

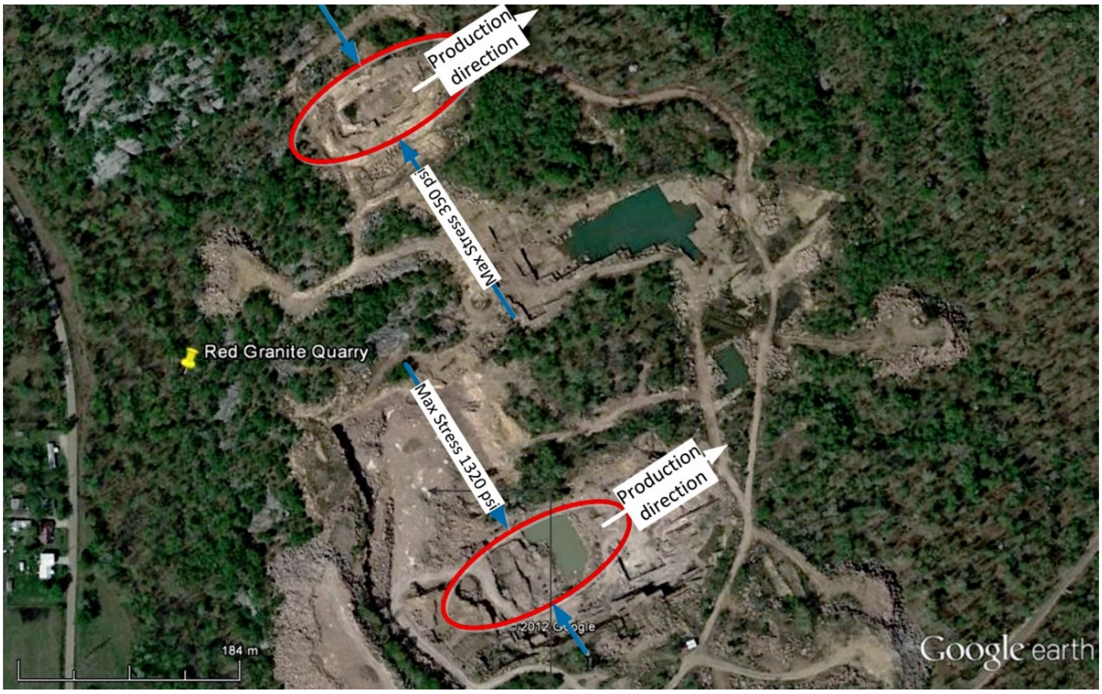

Figure 7 Maximum horizontal stress direction and magnitude

The measurement area for open pit-2 was smaller than that of Open pit 1 less difficulty was encountered during manual measurement in open pit-2 when compared to open pit-1. 60 LIDAR and optical measurements were obtained. Three dominant joint sets were observed from both the field and LIDAR-optical measurements. Lower hemispherical stereographic projection plots of the field and The three dominant discontinuity sets have mean orientations of; 87/243, 7/66, and 88/148 for manual field measurement and 86/239, 8/68 and 87/145 for LIDAR-optical field measurement.

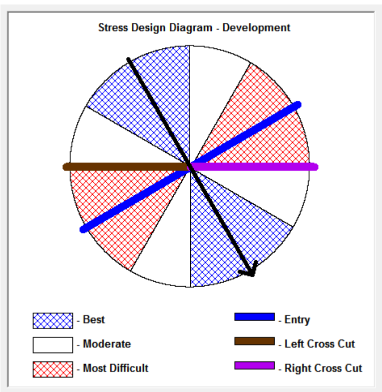

Figure 8. Stress Design Diagram Open pit-1. (Black arrow: Max. stress direction, blue line: present production line

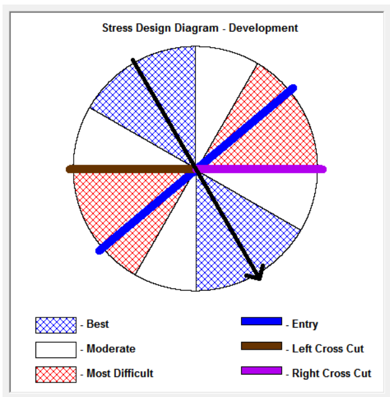

Figure 9. Stress Design Diagram Open pit-2. (Black arrow: Max. stress direction, blue line: present production line

Results of manual and LIDAR-optical methods in both open-pit 1 and open pit 2 were very close. However, as shown in open pit-1, difficulties in manual methods in field resulted in the lack of measurements at the upper area of the rock face. This is a very important problem for engineering design projects, and again justifies, the fact that LIDAR-optical method is more advantageous in determining discontinuity orientations than the manual method.

According to the results, present production direction for each pit is not good. Because maximum stress direction is perpendicular with production direction. This case is caused Unintentional breakage results in the loss rock. The results show that production direction should be changed. Depending on the stress measurements results, production directions of the proposed are shown in Figure 8-9.

4. Conclusions and Comments

In this study two methods, a manual and a LIDAR-optical based were used to estimate joint orientations in the Red Granite Quarry located in Missouri, USA. Comparison of the joint orientation results showed that the manually measured results are very close to the LIDAR-optical measurements. However, disadvantages of the manual measurement, such as time consuming, bias sampling, and risk from fallen rocks were encountered during manual measurements in Open pit-1 field.

Results of this study shows that LIDAR-optical measurement method is more advantage than manual (compass) measurement. Joint orientation data obtained from the LiDAR were quick and easy to collect, and also more accurate when compared to the manual method.

According to the stress measurements results, currently mining operation direction for each pit is not sustainable. Because maximum stress direction is perpendicular with operation direction. Therefore, operation direction must be changed. New direction of the production method should be planned as to be same direction of the maximum

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