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Pillar Failure Analysis and In Situ Stress Determinations at the Fletcher Mine Near Bunker, Mo.

UNITED STATES DEPARTMENT OF THE INTERIOR

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PILLAR FAILURE ANALYSIS AND IN SITU STRESS DETERMINATIONS AT THE FLETCHER MINE NEAR BUNKER, MO.

by

Frank G. Horino[1] and James R. Aggson[2]

ABSTRACT

A rock mechanics program (composed of laboratory and field tests) was initiated by the Bureau of Mines in an effort to determine the causes of pillar instability at the Fletcher mine, near Bunker, Mo. Compressive strength, Young's modulus, shear strength, and the angle and coefficient of internal friction were determined on drill cores obtained from 16 different locations in the mine.

Results of the laboratory tests showed that highly mineralized zones and brecciated zones in pillars could significantly affect pillar strengths and stability in locations where extraction ratios exceeded the normal design ratio of approximately 78%. High-angle fractures that were present in some locations also may have contributed to pillar deterioration.

In the field tests, in situ stress determinations were made in one pillar to establish the pillar-loading conditions and to evaluate the stability of the pillar. Continued monitoring of stresses in the pillar showed a gradual decrease in compressive stress, indicating that the pillar was probably in the postfailure state. A second stress determination was made in a vertical hole in the underlying igneous rock that was exposed on one section of the mine. Horizontal stresses were compressive and larger than would be expected from gravity loading.

INTRODUCTION

This investigation was to evaluate pillar instability at the Fletcher mine of the St. Joe Minerals Corp. and to suggest possible corrective techniques. The information obtained from this investigation can be applied to other lead-zinc mines concerned with the problem of pillar instability.

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A preliminary onsite tour of the mining location showed the presence of vertical-failure fractures existing in some of the pillars. Previous work by the Bureau of Mines has shown high-angle fractures from the horizontal can have a tremendous effect on the load-carrying capabilities of a pillar. Laboratory model studies have shown (4)[3] that pillar strengths are reduced as much as 70% by the presence of these fractures. Also, the onsite tour indicated that brecciated zones and highly mineralized zones were intersecting some pillars. These features represent other forms of discontinuities that can adversely affect the load-carrying capabilities of pillars. The purpose of the experimentation was to determine the extent and effect these discontinuities (the fractures, the brecciated zones, and the highly mineralized seams) have on the pillars, to evaluate extraction ratio and loading conditions in pillars, and to evaluate the resulting pillar stability. Under a cooperative agreement, the St. Joe Minerals Corp. provided the core to be tested, as well as the assistance needed for the in situ stress determinations. The Bureau of Mines measured the rock properties and provided the data analysis of both the properties and the in situ stress determinations.

ACKNOWLEDGMENTS

The authors wish to thank the St. Joe Minerals Corp. for the cooperation extended to the Bureau of Mines and the use of its facilities.

TEST SAMPLES

A total of 280 NX (2-1/8-inch diameter) core samples from 16 locations were obtained by St. Joe Minerals Corp., encased in plastic tubing, and provided to the Bureau. The samples were typical of the mining zone in that some contained a low mineral content while others contained a high mineral content. Some samples were from brecciated zones, and some samples contained fractures at varying angles. A few of the samples contained fractures that had been recemented. The assumption was made that these samples might fail easily and be a possible cause of the pillar instability. However, later testing proved that the recemented samples were as strong as the unfractured core samples.

SAMPLE PREPARATION

Samples were cut to the lengths desired, and the ends were surface finished with a grinder. End planes were made parallel within a 0.001-inch tolerance. Lengths of the cores were kept within a length tolerance of 0.1 inch for the length-to-diameter (L:D) ratio specified. Perpendicular tolerance of the end planes to the axis of the specimen was less than 1°.

Drill cores were categorized by L:D ratio, planes of weakness at a given angle, and highly mineralized zones. Core sample categories are given in table 1.

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[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

TABLE 1. - Core sample categories

Category	Description
1..............	L:D = 2.5:1 with plane of weakness at 30° from axis of core.
2..............	L:D = 2.5:1 with plane of weakness at 45° from axis of core.
3..............	L:D = 2.5:1 with no plane of weakness.
4..............	L:D = 1:1 with plane of weakness at 30° from axis of core.
5..............	L:D = 1:1 with plane of weakness at 45° from axis of core.
6..............	L:D = 1:1 with no plane of weakness.
7..............	L:D = 2.5:1 with highly mineralized zones equivalent to what is present in the mine.
8..............	L:D = 1:1 with highly mineralized zones equivalent to what is present in the mine.

Length-to-diameter ratios of 1:1 and 2.5:1 were selected for testing, because these dimensions best fit the in situ pillars at the time of the first benching and final pillar heights. The number of test samples from each test site location are shown in table 2.

TABLE 2. - Recovered core from locations

Location	L:D = 2.5:1			L:D = 1:1		
	Number of cores with no fractures	Number of cores with 30° and 45° fractures	Number of cores typical of mine mineralization	Number of cores with no fractures	Number of cores with 30° and 45° fractures	Number of cores typical of mine mineralization
1, 2.......	6	2	-	9	4	-
3..........	6	-	-	6	3	-
4..........	7	1	1	12	1	-
5..........	2	-	-	6	-	-
6..........	4	-	3	8	-	-
7..........	-	1	6	5	4	4
8..........	-	2	10	5	-	1
9..........	2	-	7	4	3	1
10..........	9	-	3	5	-	3
11..........	4	-	4	12	-	6
12..........	5	-	8	8	-	-
13..........	4	-	4	14	-	1
14..........	5	2	5	5	-	7
15..........	-	-	8	14	-	3
16..........	-	-	3	2	-	-
Total....	54	8	62	115	15	26

As shown in table 2, the majority of the samples fall into two groups: (1) samples with L:D = 2.5:1 and 1:1 with no fractures and (2) samples with L:D = 2.5:1 and 1:1 typical of the highly mineralized zones in the mine. A total of only 23 samples containing planes of weakness with 30° or 45° angles were received and tested.

DATA AND ANALYSIS

The samples were tested uniaxially and triaxially at lateral pressures of 500, 1,000, 1,500, 2,000, and 3,500 psi. The stiff-testing machine used for determining mechanical properties in both the prefailure and postfailure state is a closed-loop, servocontrolled hydraulic system. In a closed-loop system, the maintenance of the desired parameter is done completely by electronics and at a response rate of several kilohertz per second. The mode of control used was the feedback transducer. Results of solid-core tests were analyzed using the techniques of mean normal stress and maximum shear stress. The data were treated statistically, and a least-squares analysis was used to generate a Mohr's envelope, which gave the values of the compressive strength, shear strength, angle of internal friction, and the coefficient of internal fraction. Since the number of cores received containing apparent planes of weakness was very limited, no statistical analysis of the results could be made. However, recemented fractures had little if any bearing on the strength of the specimens tested. Test data are presented in tables A-1 through A-15 for each site location. Pertinent information regarding a location is given on the bottom of tables A-1 through A-15. Young's modulus for prefailed rock was determined at each of the designated pressures for each location and for each category of rock classification. If a rock is competent and does not contain discontinuities, Young's modulus is expected to vary slightly with an increase in lateral pressure. (See figure 1.) This is apparent when all of the Young's modulii are averaged for a given location and the standard deviation is determined.

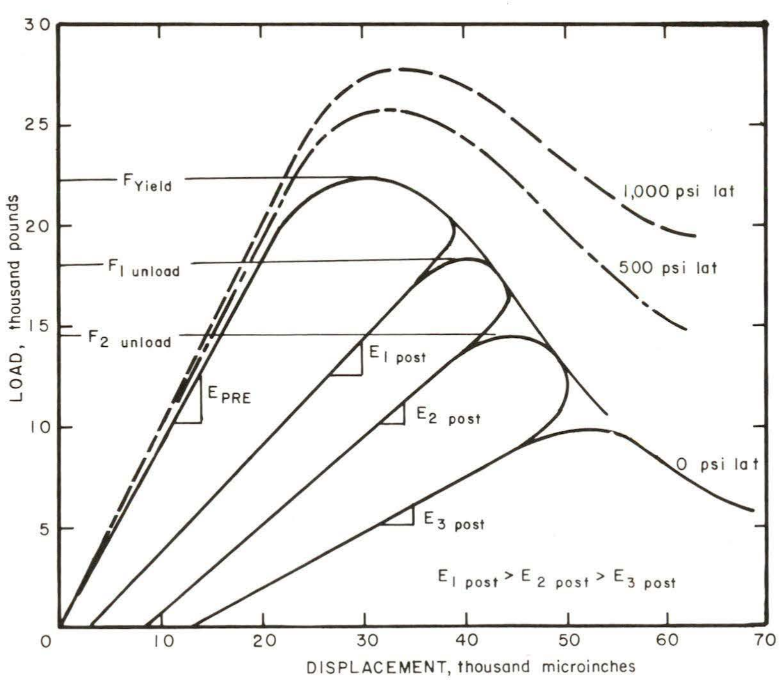

FIGURE 1. - Idealized force-displacement curve for prefailure and postfailure conditions.

On the postfailure side of the curve, changing values of Young's modulus depend upon the degree of fracturing or stress level. (See figure 1.) Therefore, an attempt is made to determine a first-order approximation of the value of Young's modulus of the failed rock at any point along the postfailure curve. Compressive strength values range from a low of 6,300 psi (L:D = 1:1 at location 14, typical highly mineralized zone in the mine) to a high of 36,800 psi (L:D = 1:1 at location 7, typical low mineralized zone in the mine). A plot of the normalized F_{unload}/F_{yield} against the normalized E_{post}/E_{pre} value for this

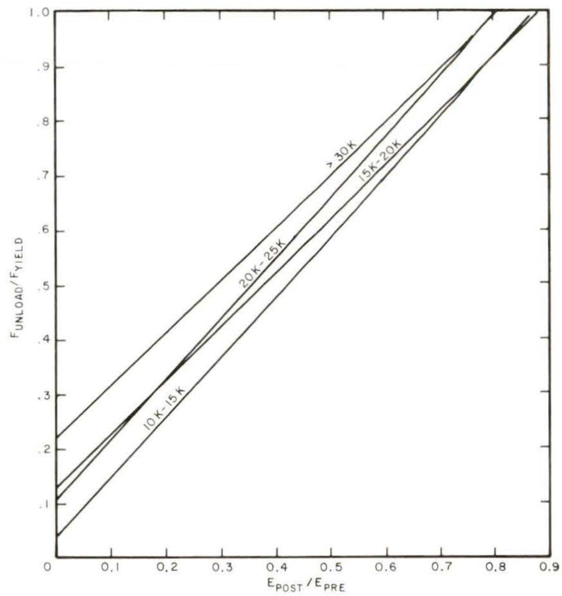

FIGURE 2. - Normalized F_{unload}/F_{yield} versus E_{post}/E_{pre} lines for zero-psi lateral pressure for all compressive strength values.

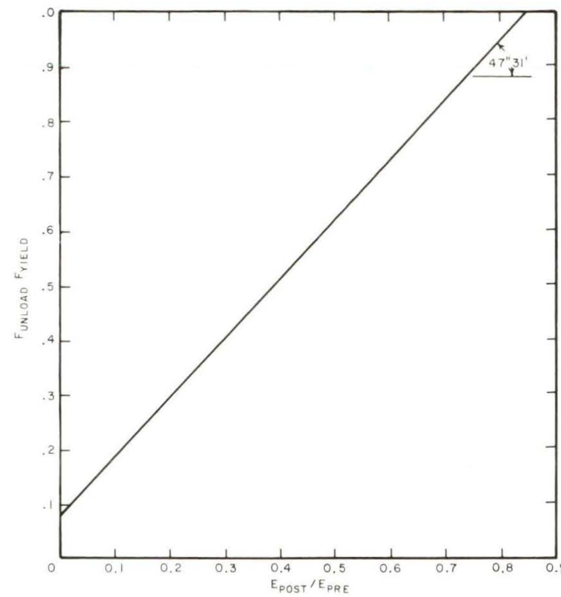

FIGURE 3. - Normalized F_{unload}/F_{yield} versus E_{post}/E_{pre} least-squares line for all data tested under zero-psi lateral pressure.

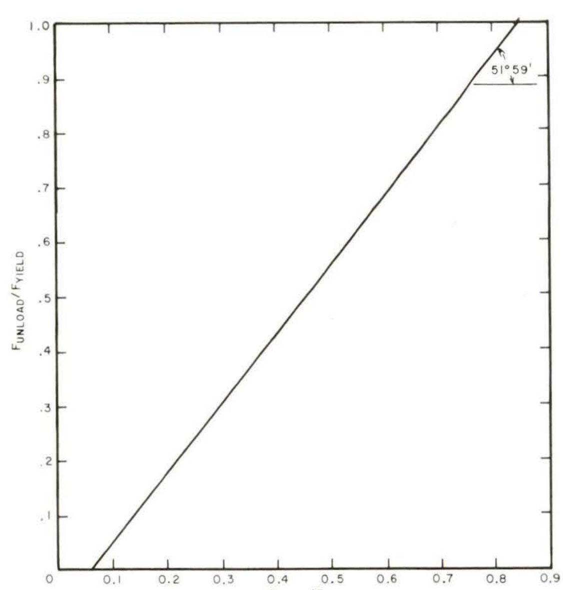

FIGURE 4. - Normalized F_{unload}/F_{yield} versus E_{post}/E_{pre} least-squares line for all data tested under 500-psi lateral pressure.

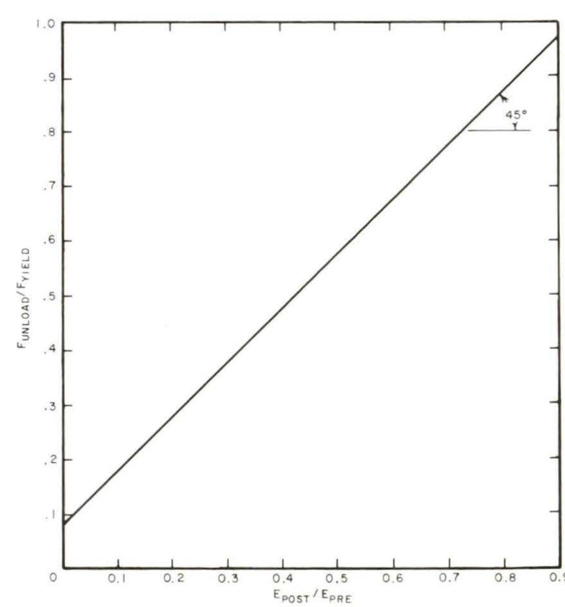

FIGURE 5. - Normalized F_{unload}/F_{yield} versus E_{post}/E_{pre} least-squares line for all data tested under 1,000-psi lateral pressure.

wide range of compressive strength values for a lateral pressure of zero psi yields a plot like that shown in figure 2. Since it appears from figure 2 that a least-squares analysis would produce a fair average line, the data were statistically treated to yield figure 3. The same technique was also used to treat the data for 500-psi and 1,000-psi lateral pressures and resulted in figures 4 and 5. Figure 4 has a negative intercept on the F_{unload}/F_{yield} axis which is meaningless and only indicates that not enough data were obtained from the postfailure curves at the lower levels of F_{unload}/F_{yield} values or at the lower E_{post}/E_{pre} values. This caused the least-squares line to have too much slope and, consequently, a negative intercept. Figure 6 was obtained by combining all the data from figures 3 through 5. This illustration could be useful in determining an approximate "E" for the design equation 9. The following rationale is based on the results of the testing:

1. It would appear that the strengths of the pillars are significantly reduced due to the high lead content of the seams, the vuggy nature of the ore rock, or the presence of high-angle joints.

2. In areas with high lead content, the ground is usually highly brecciated. Because of these two conditions, along with high axial stress, the pillars begin to deteriorate by spalling and splitting almost immediately. The loss of pillar cross section in these areas creates a much higher extraction ratio than originally designed or mined, and eventually leads to conditions of pillar instability.

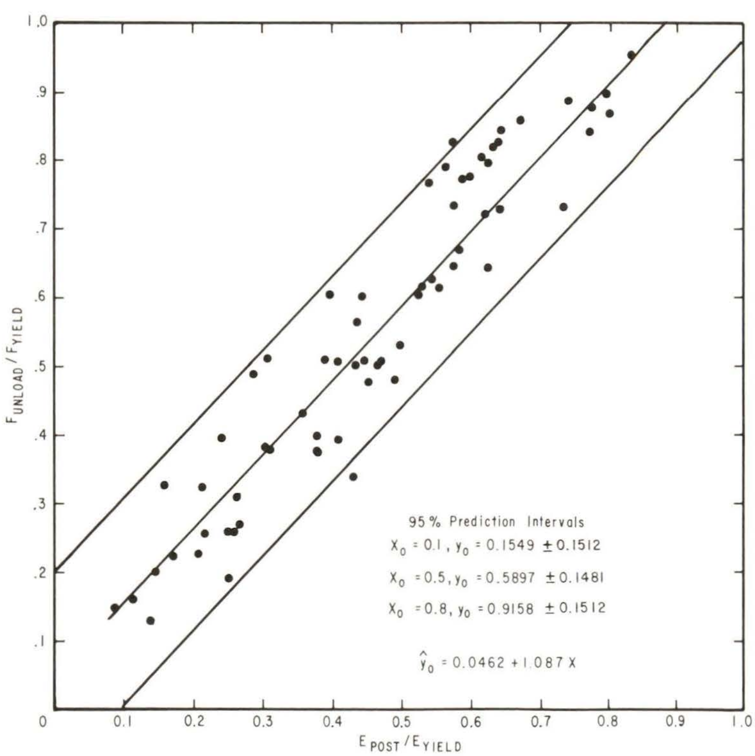

FIGURE 6. - Normalized F_{unload}/F_{yield} versus E_{post}/E_{pre} least-squares line for all data tested under 1,000-psi lateral pressure shown with 95% prediction intervals.

3. If the pillar is composed of the higher strength samples that were tested, no problems should exist for the pillar stability.

4. When dealing with a fractured rock or rock that is essentially in the postfailure region, then it is possible to design and apply pillar stabilization techniques to unstable pillars. Highly mineralized and vuggy ore samples fall into this category.

5. The average strength of the high lead

and vuggy ore samples from the 16 locations was determined to be 11,900±2,554 psi, or approximately 9,400-psi design strength. Young's modulus, E, for the material in prefailure was $(9.27 \pm 0.98) \times 10^6$ psi.

6. The average specific gravity of the samples is assumed to be 2.75. (Values of specific gravity were not calculated for the samples.)

With 28-foot-square pillars and 32-foot clear spans or 60-foot center-to-center pillar spacing, the design extraction ratio is 76%. Because of spalling, the cross-sectional area of the pillar progressively decreases and the extraction ratio increases. Since the mine is approximately 1,000 feet depth, the absolute maximum extraction ratio permissible using a safety factor of 1.0 and the average design strength of 9,400 psi can be determined. This is calculated by the following equation:

$$\sigma_{p(av)} = \sigma_v \left(\frac{1}{1-R} \right), \quad (1)$$

where $\sigma_{p(av)}$ = average pillar stress,

and σ_v = γh = vertical stress.

If γ = pounds per cubic foot,

h = depth in feet,

and R = extraction ratio,

then $\sigma_v = \dfrac{2.75 \times 62.4 \times 1{,}000}{144} = 1{,}192$ psi.

The resultant $1{,}192 \left[\frac{1}{1-R} \right] = 9{,}400$; therefore, R = 87.3%.

7. For a low strength value of 6,300 psi, the ratio 6,300/9,400 = $F_{unload}/F_{yield} = 0.67 = E_{post}/E_{pre}$.

8. From figure 6, $E_{post}/E_{pre} = 0.575$ for a horizontal stress up to 1,000 psi.

9. Therefore, $E_{post} = 0.575 \times (9.27 - 0.98) \times 10^6 = 4.77 \times 10^6$.

10. The E_{post} value should be representative of the failed material for design purposes for that location.

11. Initial inspection and observation of failed pillars indicated that the type of failure was due to pillar loads exceeding pillar strength. It was recommended that those pillars should be stabilized by confinement with fill, bolting, wire roping, strapping, or other means of applying small confining lateral pressures on the failed pillars.

IN SITU STRESS DETERMINATIONS

In situ rock stress measurements, using a three component borehole deformation gage (1), were obtained in pillar 443. Overcoring was conducted in a borehole that was drilled horizontally at the midheight of the pillar. This hole was extended to a depth greater than half the width of the pillar.

The 6-inch-diameter core tended to disk along the entire length of the hole. Disking of rock cores refers to the formation of disks or wafers of relatively uniform thickness that fracture or rupture on surfaces approximately normal to the axis of the core. Investigations have shown that core disking is a function of axial stress, radial stress, and physical properties of the material in rock (6-7). If the material properties of a particular rock are known, core disking can be used to calculate the lower limits of the applied stress field. Conversely, disking can be used to estimate material properties if the stress field is known.

Core recovery during overcoring was poor; therefore, only two sets of usable borehole deformation data were obtained from the pillar. Secondary principal stresses in the plane normal to the borehole have been calculated (2) from the two sets of deformation data and found to be

$$\sigma_v = -10{,}048 \text{ psi},$$

and

$$\sigma_h = -3{,}701 \text{ psi},$$

where σ_v and σ_h are the vertical and horizontal pillar stresses, respectively. The negative sign is used to denote compressive stress.

The average normal stress in the plane perpendicular to the borehole is -6,874 psi. For most rock types, the normal stress perpendicular to the core must be greater than one-half the unconfined compressive strength of the rock in order for disking to occur (6). The physical property results presented indicate that the same relationship could exist in the rock type found in this mine. However, since the properties of the rock in this mine vary significantly as a function of lead content, and the physical properties of the material at the midheight of the pillar were not determined, further conclusions regarding the stress-to-strength relationship and disking cannot be developed. Since core disking in various degrees was encountered throughout the length of the hole, the ratio of pillar load to material strength is larger than would be required for long-term pillar stability.

The measured vertical stress of -10,048 psi in the pillar is within the average compressive strength range of 11,900±2,554. The core disking experienced in the pillar indicates that continual spalling and pillar deterioration may be experienced (6). This deterioration will increase the vertical stress in the pillar. Since the pillar stress is nearly equal to the average compressive strength of the rock samples that have been tested, the strength of the material in the pillar may be exceeded by the vertical stress. The possibility exists that the pillar stress has already exceeded the pillar strength and that the pillar is in a postfailure state.

After overcoring was completed, a two-component borehole-deformation gage was placed in the remaining 1-1/2-inch pilot borehole in the pillar. This gage was oriented so that changes in vertical and horizontal stress could be monitored as a function of time. If pillar deterioration were increasing the vertical stress in the pillar, the two-component gage would be able to measure the changes in pillar load.

During the 45-day period after overcoring in the pillar was completed, the two-component gage measured deformations that were due to a decrease in the vertical and horizontal compressive stress. The compressive stress decrease in the vertical direction was 162 psi and the decrease in compressive stress in the horizontal direction was 165 psi. These stress changes are small compared with the measured stress magnitudes. However, it is significant to note that the stress changes are in a direction that is tending to decrease the compressive stress in the pillar. A decrease in compressive pillar stress is a strong indication that the pillar is in a postfailure state. (1). Pillar stabilization would appear to be warranted in this situation.

What appears to be an economically feasible method of pillar stabilization was, subsequently, developed for use in this mine (8). This method utilizes a system of grouting reinforcing bars into pillars in a preselected pattern. The grouted-reinforing-bar system provides sufficient reinforcement in the pillar to stop further pillar deterioration.

The secondary principal stresses in the horizontal plane were measured in the igneous rock that underlies the ore body and is exposed in the west end of the mine. This was accomplished by overcoring in a hole that was drilled vertically down. The horizontal secondary principal stresses that exist at this location are -3,949 psi and -1,862 psi. The maximum compressive stress in the horizontal plane (-3,949 psi) has a bearing of north 17° west. The measured horizontal stresses are larger than the expected horizontal stresses due to gravity loading. This result is consistent with many other stress measurements made in locations both underground and on the surface (3) in other mines. The part of the horizontal stress field that exceeds the expected horizontal stress due to Poisson's effect and gravity loading is termed "excess horizontal stress" and is presumed to be of tectonic origin.

SUMMARY

The results of the test on the 280 cores indicated that the primary cause of pillar instability was the presence of very rich lead seams and the vuggy nature of ore rock. The presence of critically oriented fracture systems can create a problem of instability; however, the primary cause of instability in this mine was the high lead content of the ore rock. An average compressive strength value of 11,900±2,554 psi and an E value of $(9.27 \pm 0.98) \times 10^6$ psi is deduced, for the high-lead-content ore rock. Pillar deterioration in areas of high lead mineralization and brecciation creates an abnormally high extraction ratio which, in turn, accelerates the deterioration and adds to the pillar instability.

By studying the postfailure curves, one is able to relate the value of the postfailure E to the value of the postfailure load. By normalizing the postfailure load to the load at yield, one finds a one-to-one correspondence of the normalized Young's modulus, $E_{post}/_{pre}$. One is able to predict the postfailure E by making the assumption that the rock core tested is the post-failure state, and its value of compressive strength is some percentage of the average low value (11,900 - 2,500 = 9,400) as determined by our testing. The curve presented also gives a percentage value of the average low value of Young's modulus, (9.27-0.98) $\times 10^6$ psi, which should be used for design purposes for that location.

In situ stress measurements in pillar 443 indicate a compressive vertical pillar stress load of -10,048 psi. This stress level is within the average compressive strength range of 11,900$\pm$2,554 psi. This information and the core disking experienced in the pillar are indications that the load-to-strength ratio of the pillar is greater than would be required for long-term pillar stability.

The horizontal stress distribution in the Precambrian igneous basement rock was measured and found to have compressive secondary principal-stress magnitudes of -3,949 psi and -1,862 psi, with the large compressive stress bearing north 17° west.

CONCLUSIONS

The lower strengths of the high lead content and vuggy core samples, the higher extraction ratio caused by the spalling action of the pillars, and the resulting high pillar stresses have created a condition of pillar instability. For spalling pillars, confining support was recommended to stabilize and control the deterioration process of failed pillars.

Study of assay values of drill cores prior to mining should indicate areas of potential problems because of the relationship of high lead content to pillar instability.

The current pillar stabilization techniques that are being used in the mine (8) apply to pillars that visually indicate deterioration. The same technique could be more effective or done at a lesser cost if the grout-rebar system were applied to the pillar immediately after pillar formation. The effectiveness of this system would be increased because the outer part of the pillar would be strengthened before it was allowed to deteriorate, and this would result in a higher overall competence. Pinning the pillar early would also prevent reduction in pillar dimensions which causes an increased load on the pillar. It is also possible that early reinforcement of the pillar would result in a cost savings by reducing the number of reinforcement bars required. It is not implied here that all pillars would need to be reinforced; however, pillars that are formed in areas of unusually high mineral content should be stabilized.

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APPENDIX

Tables A-1 through A-15 refer to locations 1 through 16. Additional information about the cores tested at a given location is noted at the bottom of each table.

TABLE A-1. - Physical properties of cores from locations 1 and 2, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..	16,400		22,400		[1]20,400
Young's modulus × 10^6.......psi..	11.31		8.51		9.11
Standard deviation..............	±1.25		±0.63		±0.81
Shear strength..............psi..	2,369		3,530		2,672
Angle of internal friction..............degrees..	57° 42'		55° 41'		59° 16'
Coefficient of internal friction.	1.582		1.465		1.683

[1]Recemented 30° fracture had no influence on strength of 1:1 pillar.

NOTE.--Two samples with L:D = 2.5:1 and with 30° fracture tested at 500-psi lateral pressure and 1,500-psi lateral pressure yielded compressive strength values of 17,200 and 27,000 psi, respectively.

TABLE A-2. - Physical properties of cores from location 3, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..	10,200		13,000		
Young's modulus × 10^6.......psi..	7.80		7.57		
Standard deviation..............	±2.62		±2.07		
Shear strength..............psi..	1,948		1,378		
Angle of internation friction..............degrees..	47° 44'		66° 9'		
Coefficient of internal friction.	1.100		2.262		

NOTE.--Most important characteristic of the tests at this location is the tremendous influence of the high lead content on the capability of the pillar to withstand load.

Two samples with L:D = 1:1 and with 30° fracture tested at lateral pressures of 1,000 psi and 2,000 psi yielded compressive strength values of 34,000 and 33,000 psi, respectively.

TABEL A-3. - Physical properties of cores from location 4, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..	26,200		31,200		
Young's modulus × 10^6.......psi..	11.68		9.91		
Standard deviation..............	±0.91		±0.81		
Shear strength.............psi..	4,510		4,805		
Angle of internal friction..............degrees..	52° 11'		56° 6'		
Coefficient of internal friction.	1.289		1.488		

NOTE.--A single test of a sample with a 20° fracture, L:D = 2.5/1, at a lateral pressure of 500 psi resulted in a compressive strength of 5,357 psi whereas, another sample with a 30° fracture, L:D = 1:1 at a lateral pressure of 500 psi resulted in a compressive strength of 30,500 psi.

TABLE A-4. - Physical properties of cores from location 5, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..			18,600		
Young's modulus × 10^6.......psi..			7.98		
Standard deviation..............			±1.38		
Shear strength.............psi..			2,725		
Angle of internal friction..............degrees..			58° 12'		
Coefficient of internal friction.			1.614		

NOTE.--Two samples from this location with a high lead content again showed the effect of the high lead content on the ability of the pillar to carry load. With lateral pressures of 1,000 and 1,500 psi, the compressive strength values were only 16,000 psi and 16,500 psi, respectively, which are less than the uniaxial compressive strength value.

TABLE A-5. - Physical properties of cores from location 6, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..	28,000	9,200	30,400		
Young's modulus × 10^6.......psi..	11.71	10.77	9.70		
Standard deviation..............	±0.28	±0.85	±0.58		
Shear strength..............psi..	4,429	1,073	4,796		
Angle of internal friction...............degrees..	55° 5'	64° 9'	55° 5'		
Coefficient of internal friction.	1.433	2.065	1.433		

NOTE.--The vertical fractures present in the samples with an L:D = 2.5:1, typical, had a deteriorating effect on the compressive strength value as indicated.

TABLE A-6. - Physical properties of cores from location 7, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..		18,800	35,200	36,800	30,200
Young's modulus × 10^6.......psi..		10.84	10.04	9.65	10.00
Standard deviation..............		±0.77	±0.36	±0.34	±0.32
Shear strength..............psi..		2,080	6,036	7,002	5,091
Angle of internal friction...............degrees..		65° 30'	52° 11'	48° 35'	53° 7'
Coefficient of internal friction.		2.195	1.288	1.133	1.333

NOTE.--The presence of the fractures in the samples with an L:D = 1:1 had little effect on its compressive strength value which would indicate that the fractures were very well cemented.

TABLE A-7. - Physical properties of cores from location 8, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..		11,000	21,200		
Young's modulus x 10^6.......psi..		9.05	9.00		
Standard deviation..............		±1.27	±0.73		
Shear strength..............psi..		2,075	3,391		
Angle of internal friction...............degrees..		49° 28'	55° 8'		
Coefficient of internal friction.		1.169	1.433		

NOTE.--The vuggy nature of the specimen with an L:D = 2.5:1 and typical of the mine has a very definite negative effect on the ability of the pillar to carry load.

TABLE A-8. - Physical properties of cores from location 9, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..	[1]19,200	12,800	21,200		25,200
Young's modulus x 10^6.......psi..		9.45	9.02		8.48
Standard deviation..............		±1.05	±0.64		±1.25
Shear strength..............psi..		2,180	2,927		5,193
Angle of internal friction...............degrees..		53° 7'	59° 19'		45° 19'
Coefficient of internal friction.		1.333	1.685		1.008

[1]One sample value.

NOTE.--Vuggy nature of core samples typical of the mine for L:D = 2.5:1 again reflects its negative effect on the compressive strength. One high lead sample, No. 111, had a compressive strength value of 12,900 psi at 0 lateral pressure.

TABLE A-9. - Physical properties of cores from location 10, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio 2.5:1 No fracture	2.5:1 Typical	1:1 No fracture	1:1 Typical	1:1 30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..	12,800	11,600	13,600		
Young's modulus X 10^6.......psi..	9.58	9.39	8.21		
Standard deviation...............	±1.53	±0.49	±1.10		
Shear strength..............psi..	2,821	2,157	1,969		
Angle of internal friction..............degrees..	42° 51'	50° 21'	58° 13'		
Coefficient of internal friction.	0.927	1.207	1.614		

NOTE.--Vuggy characteristic is the predominant factor at this location and very visibly affects the compressive strength values.

TABLE A-10. - Physical properties of cores from location 11, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio 2.5:1 No fracture	2.5:1 Typical	1:1 No fracture	1:1 Typical	1:1 30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..	10,200	14,000	14,800	15,200	
Young's modulus X 10^6.......psi..	8.82	8.69	8.01	7.70	
Standard deviation...............	±0.97	±0.11	±0.98	±1.08	
Shear strength..............psi..	1,813	3,409	2,437	3,259	
Angle of internal friction..............degrees..	51° 16'	38° 19'	53° 8'	43° 38'	
Coefficient of internal friction.	1.247	0.790	1.333	0.953	

NOTE.--Vuggy nature of core samples and its effect is pronounced at this location.

TABLE A-11. - Physical properties of cores from location 12, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..	22,000	12,200	30,400		
Young's modulus × 10^6.......psi..	10.75	8.30	9.64		
Standard deviation..............	±0.85	±1.11	±0.39		
Shear strength..............psi..	3,972	2,444	4,719		
Angle of internal friction...............degrees..	52° 11'	46° 53'	55° 5'		
Coefficient of internal friction.	1.289	1.068	1.433		

NOTE.--Samples with an L:D = 2.5:1, typical of the mine, with a high lead content and vuggy structure, clearly indicate the low compressive strength.

TABLE A-12. - Physical properties of cores from location 13, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..	15,600	14,400	23,200		
Young's modulus × 10^6.......psi..	11.13	9.02	9.24		
Standard deviation..............	±1.77	±0.68	±1.55		
Shear strength..............psi..	2,450	2,528	3,211		
Angle of internal friction...............degrees..	55° 5'	51° 16'	59° 19'		
Coefficient of internal friction.	1.433	1.246	1.685		

NOTE.--One sample, No. 179, not used in the least-squares analysis, gave a compressive strength value under 3,500 psi. One other sample with vuggy structure and high calcite content gave a value of 15,800 psi under a lateral pressure of 3,500 psi which is very low.

TABLE A-13. - Physical properties of cores from location 14, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..	17,800		24,600	6,300	
Young's modulus x 10^6.......psi..	11.08		9.76	6.08	
Standard deviation..............	±1.70		±1.20	±3.56	
Shear strength.............psi..	2,693		3,508	962	
Angle of internal friction..............degrees..	57° 8'		58° 12'	57° 8'	
Coefficient of internal friction.	1.548		1.614	1.548	

NOTE.--The very high lead content, typical of the samples from this location, gave results with much variance and would indicate that it is the major factor on the stability of the pillars at this location.

TABLE A-14. - Physical properties of cores from location 15, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio				
	2.5:1		1:1		
	No fracture	Typical	No fracture	Typical	30°, 45°, and/or vertical fracture
Uniaxial compressive strength..................psi..		16,800	17,200		
Young's modulus x 10^6.......psi..		10.95	10.03		
Standard deviation..............		±1.30	±1.33		
Shear strength.............psi..		2,512	1,929		
Angle of internal friction..............degrees..		57° 5'	65° 5'		
Coefficient of internal friction.		1.545	2.154		

NOTE.--Lower lead content of the samples tested again reflect the higher compressive strength values.

TABLE A-15. - Physical properties of cores from location 16, Fletcher mine, near Bunker, Mo.

Physical properties	Length-to-diameter ratio: 2.5:1, No fracture	2.5:1, Typical	1:1, No fracture	1:1, Typical	1:1, 30°, 45°, and/or vertical fracture
Uniaxial compressive strength....................psi..					
Young's modulus X 10^6.......psi..		7.38			
Standard deviation...............		±1.84			
Shear strength..............psi..					
Angle of internal friction..............degrees..					
Coefficient of internal friction.					

NOTE.--No least squares analysis was done at this location as not enough samples were available. Compressive strength value of high lead content samples, Nos. 219 and 223, had an average value of approximately 12,000 psi.

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