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April 15, 2009

Mr. Aaron Allred
Joint Committee on Government Finance
Building 1 Room 132E
1900 Kanawha Boulevard East
Charleston, WV 25305

RE: Annual Report of Research

Dear Mr. Allred:

In compliance with West Virginia Code §22-3A-10, please accept the enclosed annual report of research conducted by the Office of Explosives and Blasting (OEB). As mandated, the research focuses on the development of scientifically based data and recommendations.

Please contact me if you, or members of the committee, have questions or need further explanation of the enclosed report.

Sincerely,

James E. Ratcliff

James E. Ratcliff
Program Manager

JER/mdf

Enclosure

REPORT
OF
LASER AND PHOTOGRAMMETRY SURVEY SYSTEMS

By:

WEST VIRGINIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
OFFICE OF EXPLOSIVES AND BLASTING

DECEMBER 31, 2008

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ABSTRACT

The use of two (2-D) and three dimensional (3-D) laser systems for blast design optimization has been in existence in the United States since 1987. Although primarily used in quarry sites, a laser profiler was tested by the Office of Explosives and Blasting (OEB) in surface coal environments to determine how well such systems might perform in blast design and possible airblast and flyrock reduction. A new technology called photogrammetry has blasting software that uses digital images to characterize rock mass and assists blasters in free face borehole placement design. The 2-D and 3-D laser and photogrammetric systems were used to measure rock mass along a highwall and front-row burden distances were determined. Burden distance is defined as the shortest perpendicular distance between the center of an explosive charge and a free face such as a highwall. A comparison of these burden measurements were conducted and found to have significant difference due to variations in the software computations and laser operator influences.

INTRODUCTION

In the early 1980s, regulatory requirements in the United Kingdom required the documentation of front row burden distance, or burden, before a blast could be initiated. This regulation was in response to increasing flyrock incidents. Specialty laser hardware and computer software was designed to safely determine burden measurements along a free face.

This technology uses a Class 1 eye safe laser that emits a pulsed beam of energy toward a target such as a highwall. An internal clock measures the “time of flight” of the pulse and calculates the distance. Using this reflectorless principle, ranges up to 2,000 feet can be obtained. Ranges depend primarily upon rock type. Rock masses associated with quarry mining such as limestone and granite have very good reflecting capabilities, while materials such as coal, shale, and sandstone are not as reflective, and surveying must be performed at closer range.

An internal encoder, compass, or inclinometer determines the vertical and/or horizontal angles. The difference between these angle indicators are accuracy. The encoders have a +/- accuracy of 0.08 degrees while the inclinometer has a +/- accuracy of 0.40 degrees. Compasses have a +/- 1 degree accuracy. The encoders also have the advantage of eliminating magnetic north dependencies. This is crucial for surveying material with magnetic properties.

The operator uses a scope or view finder to establish a series of survey points on the highwall. Once the laser beam is emitted and reflected, the distance and angle(s) to the highwall is stored in a data collector. A 2-D laser and data collector can be seen in Figure 1. Software computations will convert the distances and angles into coordinates and produce a 2-D or 3-D cross section profile of the rock mass directly in front of a borehole. The face profile printout can show a graphical interpretation and/or tabular format with an operator-assigned depth interval and the burden distance associated with that depth. Figure 2 is an image of a 2-D face profile, and shows a depth interval of one foot. As the operator cannot laser profile every square inch of highwall, software computations will interpolate between known survey points to determine coordinates of the highwall not actually surveyed. This makes it very important for the operator to take closely spaced points when surveying irregular features on the free face of the highwall. This assures that thin burdens are included on the face profile printout which helps a blaster to determine front-row borehole zones that shouldn’t be loaded with explosives.

A major differentiation by software engineers has been made between a face profile and a minimum burden profile. A laser face profile measures burdens at a 90 degree angle from any given borehole depth to the free face, while a minimum burden profile measures burdens with a 360 degree sphere of view from any given depth of a borehole. As will be shown in this report, it can be a major difference.

Environmental conditions that affect the laser impulse or equipment include dust, heavy snow, cold, fog, direct sunlight, and rock mass reflectivity. The use of heavy equipment near free faces can also limit the use of laser profilers, especially the 2-D models. Highwalls that are “spoil bound” cannot be profiled as the highwall is not exposed. The reflecting laser does not differentiate between rock or dirt, so the use of accurate drill logs is essential for reducing airblast and flyrock potential.

Figure 1 – 2-D Laser and Data Collector

Profile: 6
Profile Description: Origin
Origin: X = 0.00 Y = 0.00 Z = 0.00
Bench Height = 20.31
Stem Depth = 0.00
Drill Offset = 3.50
Drill Angle = 0.00
Hole Depth = 20.31
Calculated Sub Drill = 0.00
Total Hole Depth = 20.31

Burden Values:

Depth	Burden	
0	3.5	CREST * MIN
1	4.16	
2	4.85	
3	5.47	
4	5.24	
5	5.74	
6	6.4	
7	7.11	
8	7.81	
9	8.07	
10	8.43	
11	8.79	
12	9.06	
13	9.66	
14	10.22	
15	10.9	
16	12.14	
17	13.79	
18	14.88	
19	16.47	
20	18.05	
20.31	18.28	TOE * MAX

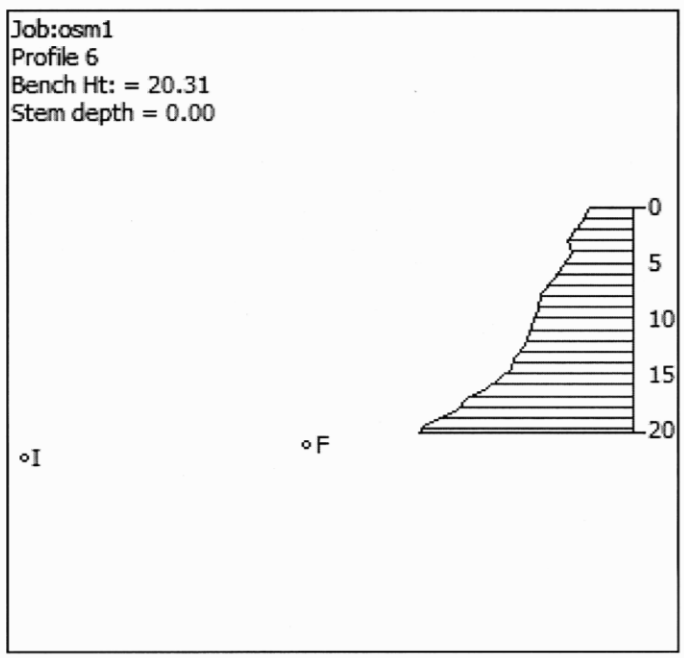


Figure 2 – Face Profile and Depth vs. Burden Table

THREE-DIMENSIONAL (3-D) LASER PROFILERS

Measurement Devices Limited (MDL) three dimensional profilers were introduced to the United States explosives markets by DuPont Explosives in the early 1980s. The Mark I profiler, designed for use in the United Kingdom, encountered problems due to a wide range of U.S. environments. Survey work in hotter environments, such as Texas, revealed failure of internal circuits due to heat transfer from the dark green metal housing. Laser profiling in frigid environments such as the iron range in Minnesota limited the ability of the operator to view the firmware commands after short periods of surveying.

The Mark II laser was launched in 1990 and incorporated an outer white metal housing and internal heater to counter the effects of heat and cold. Ensuing models (Mark III, Quarryman ALS, and Quarryman Pro) have included other features such as self-scanning, larger memory, and the ability to survey 250 points per second.

Quarryman Mark II

Quarryman Pro

Surveys are conducted by placing left and right markers at the edges of the highwall to be surveyed. These markers are used as reference points and the basis for a drill line. If the front row is already drilled, borehole locations may be surveyed. The laser operator will shoot laser points across the highwall face at specific intervals. These intervals can be taken manually by the laser operator or programmed into the laser equipment by specifying particular angular or distance requirements. Care must be taken to survey irregular features in the highwall face as many burden measurements are based upon interpolation of known survey points. Figure 4 is representative of a three dimensional laser survey.

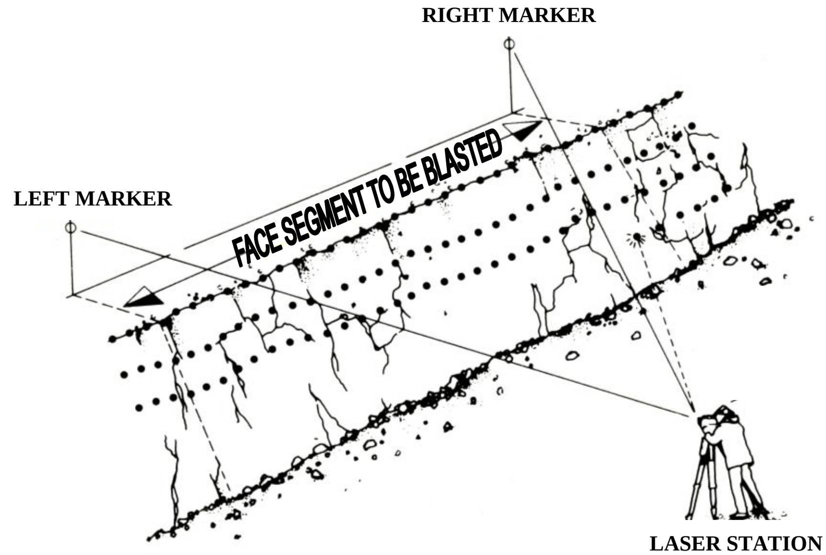
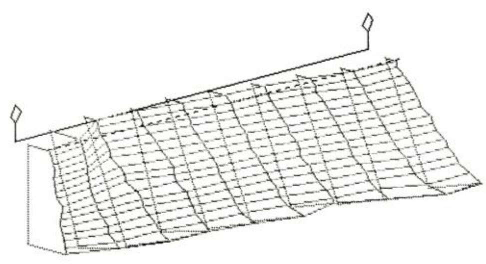
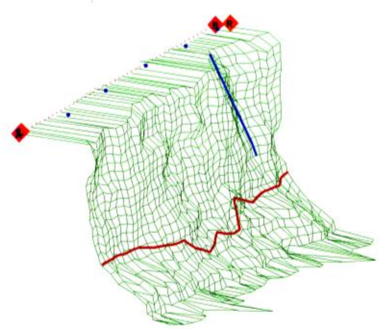


Figure 4

After the survey is conducted, data is downloaded into specialized software for blast design purposes. Three dimensional images of two separate highwalls using different blast software are shown below.

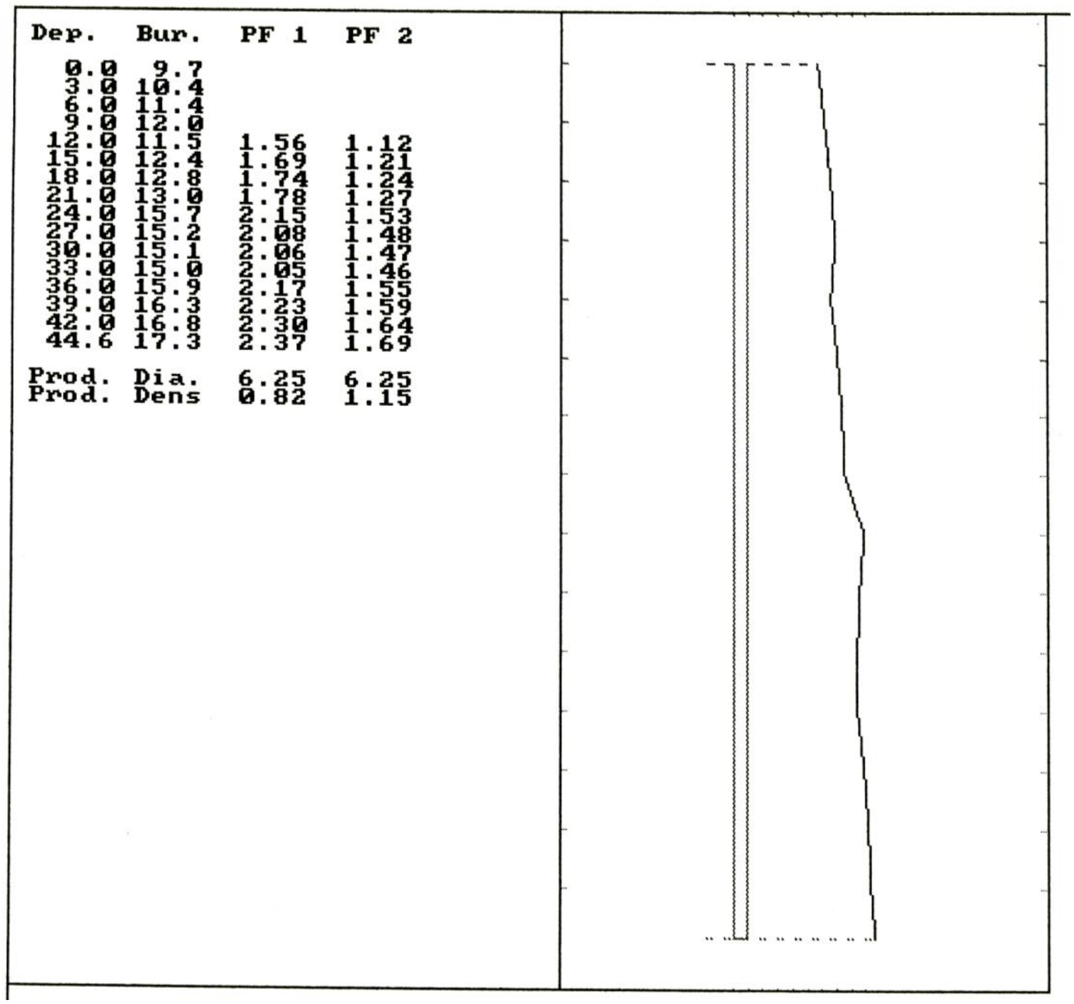




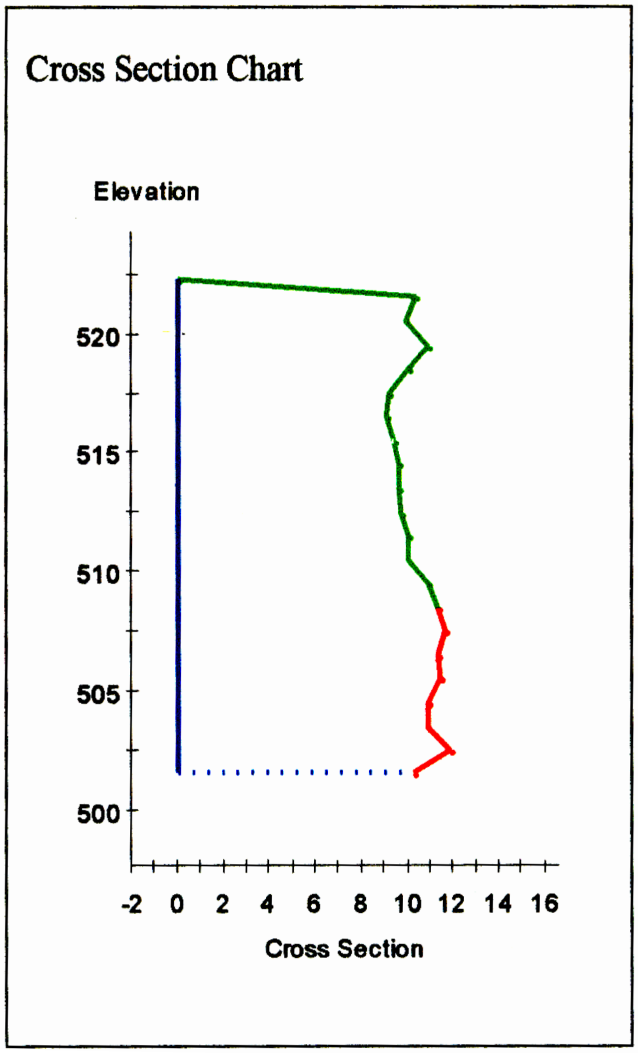
3-D View - DOS Based Blasting Software **3-D View - Updated Blasting Software**

Each 3-D view has a grid representing the highwall face. Both views indicate a drill line represented by a line between the highwall markers. This drill line is the basis for borehole placement.

Cross sections in front of actual or intended boreholes can be reviewed by the blaster and areas directly in front of the borehole with burdens not compatible with borehole diameters can have inert material (crushed stone) placed in the borehole at that location. Experienced blasters will know the minimum burden required when blasting to minimize any chances of flyrock or excessive air overpressures. Borehole cross sections created from various softwares are shown on the following page.



Borehole Cross Section DOS Based 3-D Blasting Software



Depth	Min Burden
2	9.3
4	9.3
6	9.1
8	9.2
10	9.6
12	10.0
14	10.3
16	10.3
18	10.4
20	10.3
20.7	10.3

Borehole Cross Section Updated 3-D Blasting Software

The DOS software shows depth increments of three feet and associated burdens for a forty-five foot deep hole. The updated software reveals two-foot depth increments and associated burden distances. The face profile from the DOS-based software calculates burden distances at a 90 degree angle from the borehole to the free face. This contrasts the updated 3-D and photogrammetric software which calculates minimum burden based upon a 360 degree sphere from the front row borehole.

TWO DIMENSIONAL (2-D) LASER PROFILERS

Although the original 1987 DOS based software for the 3-D laser gave detailed information to the blaster, it was not particularly user friendly. Blasters had little computer knowledge in 1987 as desktop computers had not proliferated. The fact that there could be considerable processing time for the three dimensional information, it helped spawn the development of 2-D laser systems. This was documented by Austin Powder Company[1] in 1992.

The premise that burden distances could be obtained quicker with a two dimensional laser system at the expense of more detailed information was explored. The use of a left and right marker was replaced with a single marker in front of each borehole. This is represented in Figure 5.

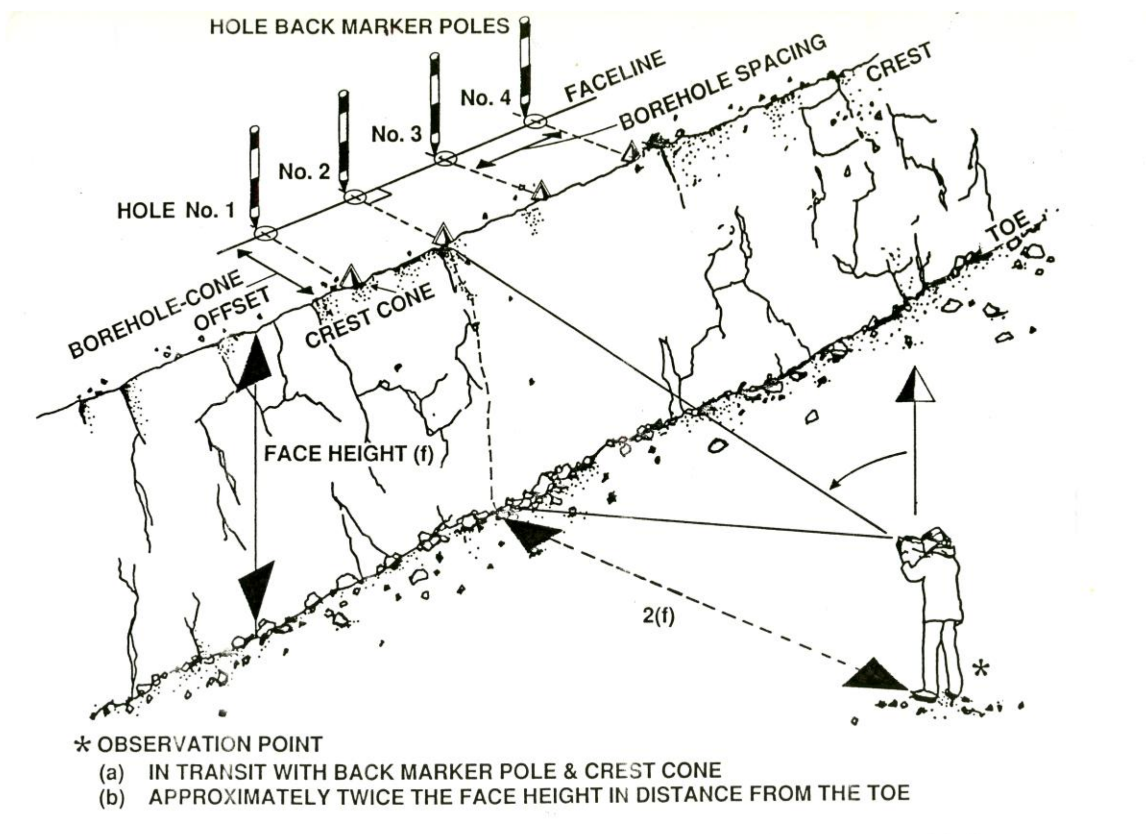


Figure 5

The laser operator was taught to align himself with the crest cone and borehole marker pole and conduct a two dimensional survey. This was found to be a good method assuming a consistent and straight highwall. This is rarely the case. Newer techniques suggest operators align themselves with the borehole marker and observed irregular areas of the highwall. This premise was tested by OEB specialists to determine the magnitude of burden variance. Figure 6 represents a simulated borehole and alignments used by OEB laser operators.

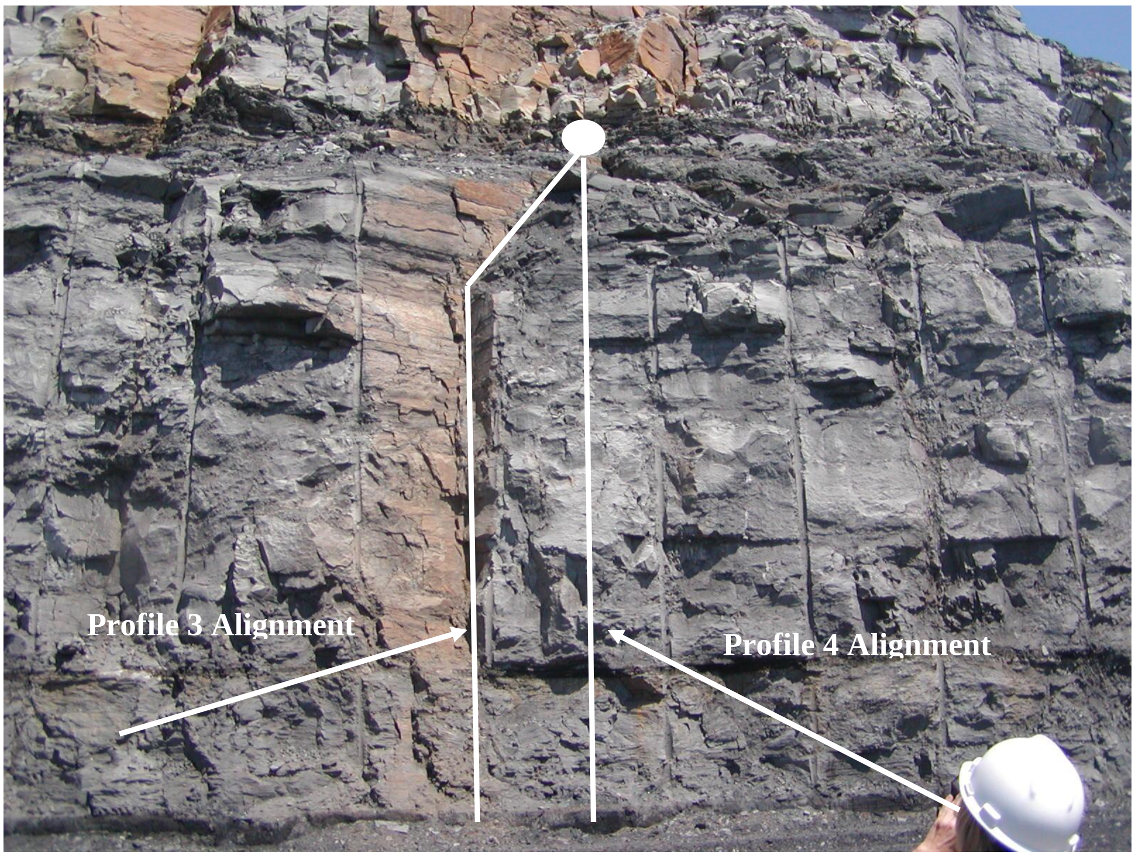


Figure 6

A two-foot crest to borehole offset was used as software input. As can be seen in Table 1, burden values can vary dramatically depending on highwall irregularities and the laser operator's face orientation. In this particular example, if a blaster has chosen to keep at least ten feet of burden between the front row borehole and free face and Profile 3 is used as a guide he would load only nine to ten feet of explosives in the borehole. If Profile 4 is used, the blaster could load approximately forty-two feet of explosives in the borehole. It is not uncommon in surface coal mines for free face holes to be drilled close to the highwall crest to "pull toe." A properly conducted 2-D laser profile and accurate drill log can help a blaster determine explosive column loads that minimize airblast and flyrock incidents.

Profile: 3-Brian (Brian Offset)	Profile: 4-Sandi
Profile Description: Origin	Profile Description: Origin
Bench Height = 51.08	Bench Height = 51.19
Stem Depth = 0.00	Stem Depth = 0.00
Drill Offset = 2.00	Drill Offset = 2.00
Drill Angle = 0.00	Drill Angle = 0.00
Hole Depth = 51.08	Hole Depth = 51.19
Calculated Sub Drill = 0.00	Calculated Sub Drill = 0.00
Total Hole Depth = 51.08	Total Hole Depth = 51.19
Burden Values:	Burden Values:

Depth	Burden		**Diff(ft)**	Depth	Burden
0	2			0	2
3	3.94		1.9	3	5.84
6	4.36		5.32	6	9.68
9	5.08		5.09	9	10.17
12	5.79		5.15	12	10.94
15	6.28		5.84	15	12.12
18	6.75		5.38	18	12.13
21	7.33		5.24	21	12.57
24	7.82		5.34	24	13.16
27	8.13		5.68	27	13.81
30	7.67		6.96	30	14.63
33	7.67		7.26	33	14.93
36	7.98		7.36	36	15.34
39	8.97		6.59	39	15.56
42	10.86		4.82	42	15.68
45	11.83		2.85	45	14.68
48	12.9		1.45	48	14.35
51	14.72		0.43	51	15.15
		Avg.	**4.86**		

Table 1 – Operator Offset versus Perpendicular Alignment

The major advantages of the 2-D laser system when compared with 3-D laser profilers are:

1) Depth versus burden tables and cross sections are immediately calculated and therefore little processing time is required. This is a big advantage in cases where profiling can only be performed just prior to blasting. Such cases include the removal of previously blasted material in front of the free face just prior to the next blast. Another possibility includes the drilling of additional free face holes while a blast is being loaded. 2-D profiles can be recalled from the data collector on the bench and printouts conducted later;
2) Blasters do not need computer or software training;
3) Equipment costs are much lower, so more laser units can be put into the field;
4) Equipment is generally much lighter and therefore more mobile. This can be helpful on contour blasts or profiling from catch benches.

The major disadvantages of the 2-D laser system when compared with the 3-D laser profilers are:

1) Blast information is not as detailed;
2) Operator must place himself in front of every borehole while 3-D systems have one setup. In cases where two free faces exist, such as a corner hole, two set-ups must be made with a 2-D system. The 3-D setup does not have to be in the immediate pit area as long as the highwall and markers can be seen and in range of the laser;
3) Borehole deviation information cannot be integrated with two dimensional laser systems;
4) Concave sections of the highwall, which represent thin burdens, may not be located in-line with front-row cones and borehole markers used in 2-D surveying. Training and experience is very important with the 2-D systems to determine the optimum location for each 2-D profile.

PHOTOGRAMMETRY

Photogrammetry is defined as the use of digital photo images to calculate the three-dimensional location of a point. Triangulation or the intersection of lines is the basis for photogrammetry and produces a two dimensional location (x,y). Photos of the same target taken from two different locations, defined as stereophotogrammetry, and the aiming direction and camera location is known, the third dimension (z) is computed. An example of a field setup for stereophotogrammetry is shown below.

As can be seen in the photos, bench and floor targets are used. The bench targets are defined as delimiters while the floor targets are called range poles. These are critical for the blasting software to be able to overlap the two photos and obtain a 3-D image. Other crucial parameters include camera calibration, complete overlapping photos, target angles, standoff distances, and size.

Photogrammetry and the corresponding blasting software have several advantages over the laser profiling system. Whereas laser profilers depend on operator experience to determine the number and location of survey points on a highwall, digital images cover the entire highwall. A camera image six inches (1200 pixels) by eight inches (1600 pixels) equates to a survey point approximately every four pixels. This is the equivalent of 480,000 survey points on the highwall. Another photogrammetric advantage is minimal time needed in front of a highwall face. Most surface coal operations have two time intervals adequate for personnel to move safely in an active coal pit environment. This is lunch break (1/2 hr.) and between shifts (1/2 hr.) This is enough time needed for range poles to be placed and two digital images to be taken. In cases where it is impractical to place range poles on the floor, they may be placed on top of the bench. A third advantage is the photogrammetric software algorithm that calculates burdens based upon a 360 degree sphere of view from the borehole. This ensures that no thin burden zones are unaccounted for by the blaster. The blasting software color codes the highwall based upon specified operator burden distances. For example, the photogrammetric image in Figure 6 shows all areas of the highwall as red with less than nine feet of burden.

Sections of highwall that have between nine and eleven feet of burden are green. All areas with more than eleven feet of burden are signified by dark blue. Software profile printouts in Figure 7 & 8 show the burden difference (metric) between a face profile (90 degree) and minimum burden profile (360 degree).

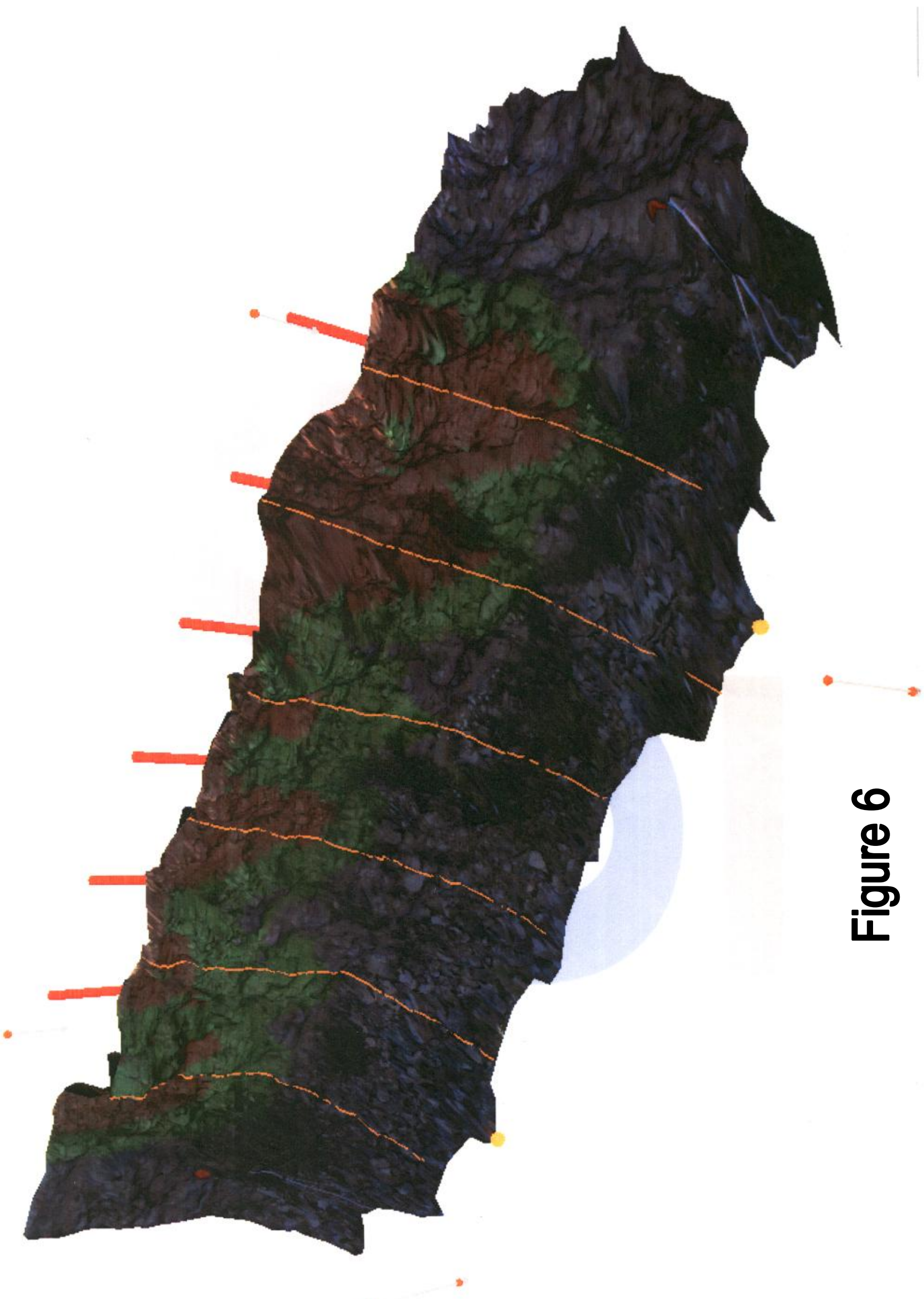


Figure 6

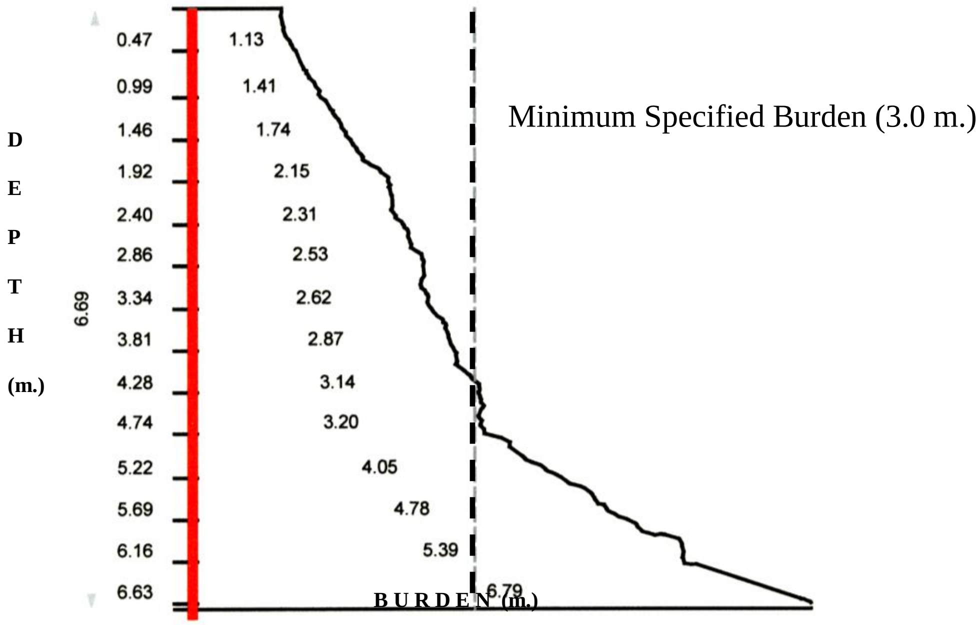


Figure 7 - Photogrammetric Face Profile

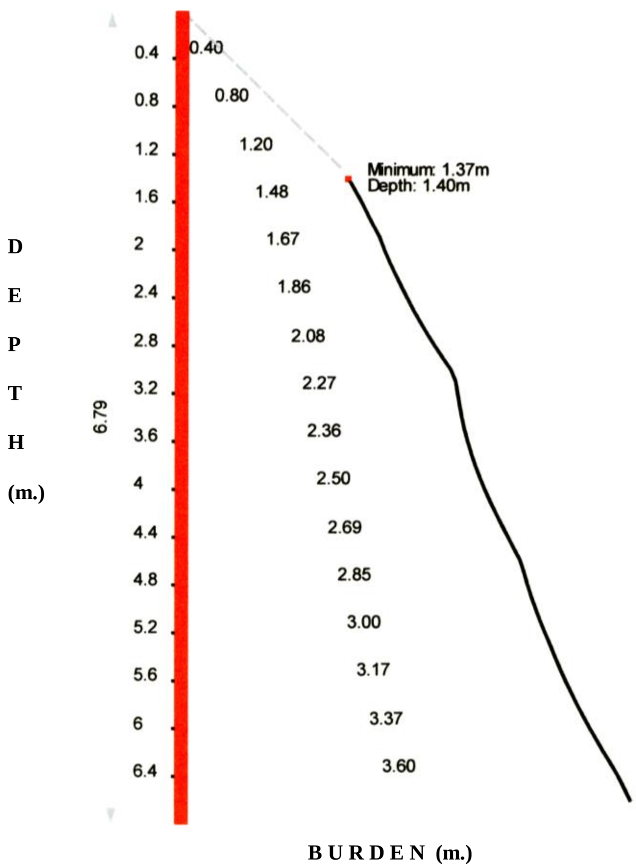


Figure 8 - Photogrammetric Minimum Burden Profile

A short term limitation of the photogrammetric software can be seen in the profiles. The current version is in metric measurements while a newer version is in imperial units. An imperial table representing the metric profiles is shown below.

Face Profile Burdens			Minimum Burdens	
Depth (ft.)	Burden (ft.)		Depth (ft.)	Burden (ft.)
1.5	3.7		1.3	1.3
3.3	4.6		2.6	2.6
4.8	5.7		3.9	3.9
6.3	7.1		5.3	4.9
7.9	7.6		6.6	5.5
9.4	8.3		7.9	6.1
11.0	8.6		9.2	6.8
12.9	9.4		10.5	7.5
14.0	10.3		11.8	7.7
15.6	10.5		13.1	8.2
17.1	**13.3**		14.4	8.8
18.7	15.7		15.7	9.4
20.2	17.7		**17.1**	**9.8**
21.8	22.3		18.4	10.4
			19.7	11.1
			21.0	11.8

As can be seen, there are significant burden differences at equivalent depths. This is attributed to the fact that the face profile burden is only measuring 90 degrees from the borehole to the free face while the minimum burden is measuring with a 360 degree sphere from the borehole to the free face.

Another photogrammetric system disadvantage is a 200-foot wide delimiter limit. This would make the photogrammetric system more time consuming to profile larger shots such as casting highwalls.

Although the current photogrammetric software can integrate only one borehole deviation measurement system, newer versions accept multiple systems.

DATA COMPARISON

An abandoned highwall was selected to compare 2-D and 3-D laser profiler and photogrammetric systems and techniques. Six simulated boreholes were marked with orange spray paint as can be seen below.

2-D and 3-D Laser Profiler Cone Set-Up

Photogrammetric Delimiter Set-Up

The two dimensional survey was conducted using an instrument on loan from The Office of Surface Mining. As part of the testing procedures, two experienced laser operators performed the survey to compare the consistency of their individual burden results. A depth interval of two feet was chosen as the highwall was between nineteen and twenty feet high. A total of 54 burden data sets (6 Holes) were compared. See Appendix. An average face profile burden measurement difference between different operators was 0.43 feet. The average burden difference was determined by taking the burden difference between the two operators at each depth for all holes and averaging these values. A minimum burden difference of 0.01 feet and maximum burden difference of 3.08 feet was determined. Tests conducted throughout 2008 between OEB blasting specialists revealed similar results. An average burden difference of 0.43 feet would indicate that two dimensional laser profilers can produce similar results regardless of the operator if the setup location is consistent.

2-D versus 3-D Burden Comparisons

A three dimensional survey was conducted using an instrument and blasting software from RAM, Inc. The blasting software computed minimum burdens except sections of the borehole designated as top stem areas. This was specified as the top four feet of borehole. A depth interval of two feet was chosen and 54 burden sets were compared. See Appendix. An average burden measurement difference of 1.50 feet was obtained. Burden measurements reveal that the 3-D burdens (minimum burdens) were consistently smaller than the 2-D burden (face profile) measurements. A minimum burden difference of 0.02 feet and maximum burden difference of 6.45 feet was calculated. This begins to show the difference between software calculations for face profile (2-D) and minimum burdens (3-D).

Photogrammetric Profile and Minimum Burden Comparisons

Photogrammetric equipment, software, printouts, and knowledge were supplied by RAM, Inc. Printouts showed both face profile and minimum burden metric measurements. Although metric depth intervals were not consistent between the face profile and minimum burden measurements, common depth intervals and burden measurements were found to compare. This was accomplished by rounding the converted imperial depths. Depth differences between the compared profile and minimum burden measurements were no more than 0.79 feet. A total of 57 data sets were compared. See Appendix. An average burden measurement difference of 2.77 feet was calculated. A minimum burden difference of 0.43 feet and maximum burden difference of 8.86 feet was calculated. These measured burden differences are large and could be very important in column load designs.

CONCLUSIONS

A comparison of laser profilers and photogrammetry systems for use in surface coal applications was conducted in 2008. Conclusions include:

1) Any use of profiling systems should incorporate accurate drill logs. Laser impulses or digital images do not differentiate between rock and dirt or cracked sections of highwalls. Geologic anomalies of specific depth and thickness are best determined and documented by drillers. High resolution photogrammetric images do allow viewing potential safety concerns such as face mud seams, cracks, voids, etc…
2) Operator training for 2-D laser surveys is more critical than 3-D or photogrammetric systems as less data points are obtained for burden measurements. Since a 2-D operator must position himself in front of each free face borehole for a vertical survey, alignment with an irregular free face is very important. Newer 3-D and photogrammetric blasting software account for highwall irregularities and subsequent burden measurements independent of operator location. Since 2-D profilers cost considerably less than 3-D or photogrammetric systems, they are more likely to be used.
3) Large burden differences can be noticed depending on blasting software algorithms. Minimum burden profiles are not only based upon burdens directly in front of a borehole, but sections of free face on either side of an actual or intended borehole. A 360 degree sphere of view at specific depth intervals is used for minimum burden measurements. Face profiles (2-D and older 3-D software) only consider burdens directly in front of boreholes.
4) Items that limit the effectiveness of 2-D or 3-D laser systems in surface coal mines include dusty environments, heavy snow or fog, cold weather, direct sunlight, rock reflectivity, and spoil bound highwalls.
5) Current photogrammetric limitations include a delimiter width of 230 feet and metric measurements. An updated software version allows for imperial measurements. Delimiter and range pole targets can be sandbagged in windy environments. In cases where range poles cannot be placed on the active coal pit floor, they can be placed on the highwall crest.
6) All of these systems assume drill holes have no deviation from their intended path. This is not always the case. The 2-D laser systems are unable to integrate any borehole deviation information as only the vertical plane is considered. 3-D blasting software has this capability. Current photogrammetric blasting software versions can integrate only one borehole deviation system, but an updated version allows multiple borehole deviation softwares.
7) Research into borehole deviations in surface coal mine environments and the effects upon free face burden distances is worthy of study. Particular emphasis should be placed on free face angled boreholes.

APPENDIX

2-D Laser (Operator Comparison)

Hole 1

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	10.19	10.30	0.11
4	9.01	9.47	0.46
6	7.58	8.72	1.14
8	9.11	9.28	0.17
10	9.47	9.49	0.02
12	9.88	9.97	0.09
14	11.81	11.96	0.15
16	14.27	14.31	0.04
18	16.82	17.45	0.63
		Avg Diff (ft.)	**0.31**

Hole 2

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	7.98	8.08	0.10
4	8.69	8.78	0.09
6	8.95	9.06	0.11
8	9.55	9.63	0.08
10	9.79	9.94	0.15
12	9.89	10.02	0.13
14	10.71	11.48	0.77
16	13.46	12.93	0.53
18	16.05	17.28	1.23
		Avg Diff (ft.)	**0.35**

Hole 3

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	7.65	7.02	0.63
4	9.33	7.50	1.83
6	11.35	8.27	3.08
8	10.36	10.13	0.23
10	10.51	10.54	0.03
12	11.01	10.86	0.15
14	12.43	12.16	0.27
16	14.04	13.48	0.56
18	16.28	15.24	1.04
		Avg Diff (ft.)	**0.87**

Hole 4

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	8.98	8.59	0.39
4	8.85	8.54	0.31
6	9.42	9.49	0.07
8	10.25	10.45	0.20
10	9.97	9.62	0.35
12	10.75	10.33	0.42
14	11.33	11.32	0.01
16	13.22	12.89	0.33
18	14.72	15.09	0.37
		Avg Diff (ft.)	**0.27**

Hole 5

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	4.85	4.44	0.41
4	5.24	5.31	0.07
6	6.40	6.98	0.58
8	7.81	7.89	0.08
10	8.43	8.57	0.14
12	9.06	9.32	0.26
14	10.22	10.18	0.04
16	12.14	12.57	0.43
18	14.88	16.14	1.26
		Avg Diff (ft.)	**0.36**

Hole 6

Depth	Operator A Burden	Operator B Burden	2D Diff. (ft.)
2	9.48	9.47	0.01
4	8.90	8.73	0.17
6	8.64	8.86	0.22
8	8.80	8.98	0.18
10	8.97	9.29	0.32
12	8.08	8.74	0.66
14	9.37	9.61	0.24
16	10.65	11.22	0.57
18	12.41	13.48	1.07
		Avg Diff (ft.)	**0.38**

2-D – 3-D Laser (Burden Comparison)

Hole 1

Depth	**Operator A 2D Burden**	**3D Burden**	**Diff. (ft.)**
2	10.19	9.30	0.89
4	9.01	9.30	-0.29
6	7.58	9.10	-1.52
8	9.11	9.20	-0.09
10	9.47	9.60	-0.13
12	9.88	10.00	-0.12
14	11.81	10.30	1.51
16	14.27	10.30	3.97
18	16.82	10.40	6.42
		Avg Diff (ft.)	**1.18**

Hole 2

Depth	**Operator A Burden**	**3D Burden**	**Diff. (ft.)**
2	7.98	8.00	-0.02
4	8.69	8.40	0.29
6	8.95	8.60	0.35
8	9.55	9.10	0.45
10	9.79	9.70	0.09
12	9.89	10.10	-0.21
14	10.71	9.80	0.91
16	13.46	9.60	3.86
18	16.05	9.60	6.45
		Avg Diff (ft.)	**1.35**

Hole 3

Depth	**Operator A Burden**	**3D Burden**	**Diff. (ft.)**
2	7.65	6.40	1.25
4	9.33	7.30	2.03
6	11.35	8.00	3.35
8	10.36	8.20	2.16
10	10.51	8.70	1.81
12	11.01	9.30	1.71
14	12.43	10.10	2.33
16	14.04	10.70	3.34
18	16.28	11.60	4.68
		Avg Diff (ft.)	**2.52**

Hole 4

Depth	**Operator A 2D Burden**	**3D Burden**	**Diff. (ft.)**
2	8.98	8.40	0.58
4	8.85	8.40	0.45
6	9.42	8.70	0.72
8	10.25	9.10	1.15
10	9.97	9.70	0.27
12	10.75	10.10	0.65
14	11.33	10.40	0.93
16	13.22	10.80	2.42
18	14.72	10.80	3.92
		Avg Diff (ft.)	**1.23**

Hole 5

Depth	**Operator A Burden**	**3D Burden**	**Diff. (ft.)**
2	4.85	4.20	0.65
4	5.24	4.90	0.34
6	6.40	5.70	0.70
8	7.81	6.60	1.21
10	8.43	7.40	1.03
12	9.06	8.20	0.86
14	10.22	9.10	1.12
16	12.14	10.00	2.14
18	14.88	9.90	4.98
		Avg Diff (ft.)	**1.45**

Hole 6

Depth	**Operator A Burden**	**3D Burden**	**Diff. (ft.)**
2	9.48	6.60	2.88
4	8.90	7.50	1.40
6	8.64	8.40	0.24
8	8.80	8.70	0.10
10	8.97	8.30	0.67
12	8.08	8.10	-0.02
14	9.37	8.30	1.07
16	10.65	9.00	1.65
18	12.41	9.20	3.21
		Avg Diff (ft.)	**1.24**

Photogrammetric Profile and Minimum Burden Comparison

Hole 1

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
1.00	10.17	1.31	8.86
3.00	9.91	2.62	7.28
5.00	9.38	5.25	4.13
8.00	9.05	7.84	1.21
9.00	9.38	8.33	1.05
11.00	9.48	8.92	0.56
12.00	9.81	9.38	0.43
14.00	11.38	9.81	1.57
17.00	14.89	10.79	4.10
18.00	17.65	11.48	6.17
20.00	20.53	12.23	8.30
		Avg Diff (ft.)	**3.97**

Hole 2

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
3.00	8.99	2.62	6.36
8.00	10.04	7.87	2.16
9.00	10.66	9.18	1.48
11.00	10.66	9.51	1.15
13.00	10.76	10.10	0.66
14.00	10.92	10.46	0.46
16.00	13.28	10.59	2.69
17.00	15.35	10.89	4.46
		Avg Diff (ft.)	**2.43**

Hole 3

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
3.00	8.04	2.62	5.41
5.00	8.10	5.25	2.85
8.00	8.89	7.87	1.02
9.00	9.58	8.50	1.08
11.00	10.63	8.89	1.74
12.00	11.48	9.28	2.20
14.00	12.40	10.27	2.13
17.00	14.24	11.41	2.82
		Avg Diff (ft.)	**2.41**

Hole 4

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
1.00	9.32	1.31	8.00
3.00	8.99	2.62	6.36
4.00	8.92	3.94	4.99
7.00	10.00	6.56	3.44
9.00	9.94	9.18	0.75
12.00	10.66	10.04	0.62
13.00	11.15	10.23	0.92
17.00	13.68	11.41	2.26
18.00	14.69	11.91	2.79
20.00	16.63	12.40	4.23
		Avg Diff (ft.)	**3.44**

Hole 5

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
3.00	4.62	2.62	2.00
5.00	5.71	4.85	0.85
8.00	7.58	6.10	1.48
9.00	8.30	6.82	1.48
11.00	8.59	7.45	1.15
13.00	9.41	8.20	1.21
14.00	10.30	8.82	1.48
16.00	10.50	9.35	1.15
17.00	13.28	9.84	3.44
20.00	17.68	11.05	6.63
		Avg Diff (ft.)	**2.09**

Hole 6

Depth	Profile Burden	Minimum Burden	Diff. (ft.)
3.00	7.81	2.62	5.18
5.00	8.07	5.25	2.82
7.00	7.84	6.56	1.28
8.00	8.40	7.64	0.75
11.00	8.63	7.48	1.15
13.00	8.04	7.35	0.69
14.00	8.43	7.58	0.85
16.00	9.38	7.97	1.41
17.00	10.17	8.56	1.61
20.00	14.46	9.81	4.66
		Avg Diff (ft.)	**2.04**

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