New Applications for Reflectorless Lasers in Drilling and Blasting

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1.0 Introduction

Reflectorless laser survey equipment has made it much easier to take accurate measurements to inaccessible locations in quarries, open pit mines and rock slopes. Prior to the introduction of the reflectorless laser as a working tool, it was not possible to directly measure to inaccessible locations on rock faces. If a person could not occupy the point, only indirect measurements could be made. For blasting work, measuring the burden in front of the first row of holes could only be done approximately, using such techniques as holding a plumb line in over the crest, triangulating in on a few points or "eyeballing" the burden. This led to direct and significant problems with blasting, including flyrock and airblast (caused by insufficient front row burden), excessive vibrations, problems with oversize and tight digging (all of which may be caused by excessive front row burdens).

In the last ten to fifteen years, a number of laser systems have been introduced on the market that allow the operator to measure the front row burden and adjust either adjust explosive loading or drill hole location accordingly. In some jurisdictions (e.g. Great Britain), the law now stipulates that before any blast can be loaded, the rock face must be completely profiled and the results used to design and load the blast so flyrock and vibration problems are minimized. These profiles become a required record the operator must keep in case of any problems. To the author's best knowledge, these type of regulations do not exist in North America, but many operations have found that profiling the face of a blast is a very useful tool to control the problems outlined above.

In addition to face profiling of blasts, reflectorless lasers have become popular tools for modeling stockpiles for improving inventory control. This paper will outline a number of existing and new applications for lasers in the blasting, quarrying and mining fields, as listed below. Examples of a number of the applications will be shown, including brief descriptions of the field techniques used to obtain these results.

- Blasting - Face profiling to control airblast, muckpile shape, flyrock and oversize
  - New techniques to better calculate actual burdens at all points on a rock face
  - Muckpile profiling to determine throw
  - Cast blasting
- Quantities - Muckpile models to determine swell and blasting effectiveness
  - Before and after ground models to measure rock quantities removed
  - Ground models to calculate available rock quantities
- Mapping - Producing maps, plans and models of quarries, construction sites and mines to aid in planning and control of operations, measuring reserves and

excavated quantities, royalty payments, etc.

- Drilling -Lasers can be used for laying out and controlling drilling in difficult terrain
- Tunneling -Profiling of tunnels and drifts in civil and mining applications for quality control, as-built measurements, quantities and contract payments
- Slope Stability -Measuring movement of rock and earth slopes over large areas
- Cavity and Void Measurements - determining the exact size and layout of inaccessible stopes, voids, openings and old mine workings

A thorough understanding of the principles of reflectorless laser equipment and various survey techniques is essential for anyone using lasers to get the most out of their system.

2.0 Principles of Reflectorless Laser Survey Equipment

There are many types of laser equipment on the market for measuring distances to rock surfaces. The simplest are laser rangefinders that measure only a distance - these can be used for approximate face height measurements. The simplest profilers are hand held units that record a distance and a vertical angle only -- applicable for producing a simple two-dimensional profile in front of a drill hole. More versatile units will record distance, horizontal and vertical angles for thousands of points, allowing production of accurate three-dimensional models. The newest laser equipment has motorized scanning capabilities. After outlining the area to be scanned, the laser unit will take all measurements automatically. This allows for fully remote operation, if desired. Some systems have now combined laser and GPS (Global Positional System) technology.

Most laser systems work on a “time-of flight” principle. The unit will send out continuous pulses of a low-powered laser beam through a transmitting lens. This beam is usually invisible to the human eye – some units have added a visible pointing laser that allows the user to see the exact point to where the measurement is being taken. By measuring the time it takes for the pulse to reflect off a surface and return to the receiving lens, the distance to the surface can be calculated accurately.

If a point has to be located in space it is necessary to know two angles as well as a distance. Two-dimensional systems used for profiling in front of a borehole measure the vertical angle only. The simplest and least expensive technique for measuring vertical angles is by using an inclinometer. More accurate vertical angles can be measured by use of encoders. If the laser is to be used for three-dimensional applications (such as profiling a complete face, ground modeling and mapping) it is necessary to measure a horizontal angle. Magnetic devices (relying on the magnetic field of the earth) are the simplest technique, but can lead to major errors if there is strong magnetic fields present generated by electrical equipment, steel structures or ferrous material in the rock mass. Angular encoders are the best system to record horizontal angles.

To understand the many applications of lasers, it is necessary to discuss the range and accuracy of a reflectorless system. The maximum range of a laser depends on many factors, the primary one being the reflectivity of the material. Ranges quoted by manufacturers are not always directly comparable. Units that can consistently measure two hundred and fifty meters to a smooth, light coloured rock may only measure eighty meters to coal. The angle the laser strikes the surface will also govern the amount of reflected energy and the distance achievable.

Accuracy of the distance measured also depends on many factors. All lasers leave a "footprint" or area the incident beam strikes. The longer the distance measured, the larger the footprint area. In the rough conditions commonly encountered in rockwork, the footprint may cover an area that is large enough to make it impossible to know exactly where the reflected signal is coming from, thus introducing a sizeable error. Commonly quoted accuracies range from 3 millimeters to 5 centimeters. Generally the best accuracy is obtained at short distances, with smooth surfaces and longer measuring times (more samples).

In this author's experience, the main errors generated in laser surveys are not in the range of the instrument but inaccuracies in angular measurements. To make accurate measurement of points on a rock face, it is essential to set up the instrument properly so angles are recorded accurately. Instruments with angular encoders commonly quote accuracies of +/- 0.02 degrees. At a distance of 300 meters, this only represents an error of 0.10 meters. However, if the instrument is not properly leveled, a setup of error of 0.5 degrees could easily occur. This will result in an error of 2.6 meters at a distance of 300 meters. Errors in vertical angle are more significant in blasting operations - if the laser is being used for layout and mapping work or profiling high faces it is easy to introduce a significant error in bench height measurements.

All laser systems are only capable of measuring a distance and one or two angles. Without appropriate software, the instrument can only act as a rangefinder. Most computer software used with laser systems converts the measured distances and angles into spatial coordinates (x and z points for 2-D systems and x, y, z points for 3-D systems) so the results can be used in different applications. Carefully consider the software available to work with your instrument. Points to be considered include:

- How the data is downloaded and changed into x,y,z format? Each manufacturer has their own techniques for this, and they are NOT always interchangeable. Data collected with one machine may not be useable with a competitor's software.
- The software selected should allow for the export of x,y,z data into other packages such as CAD and Digital Ground Modeling techniques.
- What types of survey techniques and calculations are available in the software that allow the instrument to be used for different purposes, including establishing or using existing coordinate systems?

3.0 Survey Techniques for Rock Work

There are three basic survey techniques available for blasting, quarrying and mining applications.

- Conventional methods using a two-man crew with a theodolite, EDM (electronic distance measuring) equipment and prism pole or total station
- Reflectorless laser technology
- GPS (Global Positioning System) methods

Using GPS, a surveyor carries a backpack with a GPS transponder that locates several satellites orbiting the earth. This provides a coordinate and elevation on the earth's surface for every point measured. To measure any point it is necessary to physically occupy that location with the unit.

Each system has its advantages and disadvantages. Some of the main ones (when working in the rock excavation field) are listed below in Table 1.

Survey System	***Advantages***	***Disadvantages***
Conventional Techniques (EDM)	• Very accurate • Well known technology • Works with existing survey control	• Impossible to access many locations (need to physically occupy the point) • Expensive (two person operation) • Cost per point collected is high
GPS Techniques	• Can be very accurate, depending on system used • One person operation, very portable • Automatically provides coordinates of each point collected • Faster point collection than EDM's	• Impossible to access many locations (need to physically occupy the point) • Cost per point collected is high • May be limited in time of operation and accuracy by satellite location and zones of no coverage • Cannot collect enough points to accurately model many conditions
Laser Techniques	• Usually a one person operation • No requirement to occupy point being measured (good for rock slopes, cliffs, steep hills, etc.) • Fast collection of many points • Cost per point is very low	• Slightly less accurate than EDM • Unfamiliar technology to many • Requires various survey techniques to tie information into existing plans • Easy to collect stray points that have to be edited

Table 1 - Advantages and Disadvantages of Various Survey Systems Used for Rock Work

New laser units currently under development include a GPS unit mounted with the laser. This allows the laser to locate itself on the earth's surface, gather a large number of points quickly and use this combination of information to give actual coordinates and elevations for all points gathered. At present, to achieve the accuracy necessary for many of the applications listed requires a relatively expensive GPS system.

Survey grids are commonly divided into three components - eastings (the x component on a graph), northings (the y component on a graph) and elevations (the z component). The coordinates of a point are usually expressed as an easting and a northing.

3.1 Local Surveys

This is the simplest form of surveying using a laser system. There is no relationship to actual coordinates or elevations. Instead, the instrument is switched on, various measurements are taken and the results calculated. To be able to produce x,y,z data there are usually two assumptions made:

- the instrument is assumed to be at an arbitrary point (e.g. 5000.00 East, 5000.00 North, Elevation 100.00)
- the instrument has a known orientation or bearing when it is turned on (e.g. it is assumed to be pointing north)

With these two assumptions, the location of every point measured can be calculated and displayed, using the local coordinate system.

The most common application for this type of work is face profiling. If it is not necessary to relate these results with other measurements or surveys then a local survey is all that is required. If it is necessary to be able to repeat the survey from the same location, then the best technique is to set up the instrument, mark the point on the ground and backsight a specific point (e.g. tree, structure, feature) before turning the laser on. To repeat the measurement, just set up on the same point, use the same backsight and the results will be directly comparable.

3.2 Known Surveys

With a known survey, it is necessary to relate the location of the instrument to one or more known points, so the instrument position can be calculated and the results from setups at different locations can be properly tied together. This can be done in several ways - using a foresight fix method, a traverse or by re-sectioning.

Foresight Fix - in this technique, the instrument is set up on a point (either known as an actual coordinate and elevation or assumed, as above) and a new point (station) is shot from this location. The location and elevation of this new point can be calculated by hand or by use of computer software. When the instrument is set up on this new point, the first point is backsighted. All measurements are taken with angles related to the backsight. This means the coordinates and elevations calculated from the second station are on the same grid system as those measured from the first station. When the results are calculated from both stations and are merged together, everything should match. This is an ideal technique for face profiling when it is not possible to see every area of the face from one setup.

Traverse Techniques - A traverse is created by a series of points forming a closed loop around an area. These points (or stations) are established by setting up on one, backsighting the previous point and forsighting the next one (as outlined above). This continues around the traverse, with backsights and foresights being taken from each point. When the instrument is set up on the last point, the measurement to the first point completes the traverse. This measurement is an excellent way to check the accuracy of the survey - ideally the coordinate and elevation of the first station as measured from the last station should be the same as the coordinates and elevation of the original point. Of course this rarely happens - the discrepancy between these points is known as the closure error and must be accounted for, either by correcting all of the calculated coordinates and elevations or by correcting errors made in the survey. For applications in mine, quarry and construction blasting it is not necessary to have extremely precise traverse closures. However, the location of each station is used for calculating all points measured from it, so a great deal of care should be taken to get the results as accurate as feasible, particularly if the measurements are being used for payment and inventory purposes.

Common applications for use of traverse surveying include inventory measurement (stockpiles), measuring rock volumes before and after blasting and mapping. Samples of these applications are included in the next section.

Re-sectioning Techniques - This is a very powerful survey technique that is not commonly used in the blasting field. Essentially it allows the operator to put the instrument down at any location, site three known stations and take measurements from that point. All points measured from this setup will have coordinates and elevations that match the overall coordinate system. Re-sectioning works by drawing circles around the three known stations, with radii equivalent to the horizontal distance measured to them from the instrument setup. The intercept of the three circles is where the instrument is located.

This technique is very useful for mapping and ground modeling work. During the initial survey, the operator will establish a number of stations and complete all necessary measurements from these stations. If more detail is required, rather than establishing additional stations, the instrument can be set up at the best location, three known stations shot, data gathered and the resulting measurements merged with the original data.

4.0 Examples of Lasers Technology in Blasting, Quarrying and Mining Applications

4.1 Face Profiling

By mapping a rock face in detail, it is possible to determine actual burdens in front of each borehole, including the position of the borehole itself with respect to the others. Figures 1 and 2 show examples of face profiling on a 60-foot bench. The actual drill hole locations were measured using the laser.

These results are typical face profiles that would be generated by a two or three-dimensional system, using a form of ground modeling technology. As the laser scans back and forth across the face, it measures to a series of random points, including additional details in areas where there are significant changes in face conditions. These points may or may not be directly in front of a borehole. If a two dimensional system is being used the profile shown will be of the points actually measured, whether or not they are in the right location. If a three-dimensional system is being used, the software will try to predict the burden in front of the hole by using actual nearby points and estimating the coordinates of the required points.

This technique may have a fundamental flaw under certain conditions. The point of minimum burden may not actually be directly in front of the hole, but offset to the side, depending on geological conditions, previous backbreak, the angle the laser hits the face at, etc. In these cases the burden shown by the software may be more than is the actual case, producing potential for flyrock and airblast problems.

An entirely new approach to this problem has recently been developed. "Face 3-D for Windows '95" from MDL approaches the modeling differently. All consecutive data points collected on a face are assumed to be connected by "strings". When the user wants to generate a profile in front of a hole, the profile is drawn based on every "string" that is intercepted. An intensive calculation is then done to determine the minimum burden at each point in each hole, using a tool called "Burdenmaster". This routine looks not just in front of the hole but also to each side to calculate the location of the minimum burden. Figure 3 shows an example of the results of this calculation - the minimum burden occurs at locations that are as much as 1.6 meters offset from directly in front of the hole. Note that at many locations over the profile the minimum burden is significantly less than would have been predicted with earlier techniques.

4.2 Ground Modeling for Volumetric and Casting Purposes

Lasers are a tool that can be used to accurately model ground conditions before and after a blast to determine volume of the blast (important for such issues as production requirements and payment quantities), the percentage swell (an indicator of blasting efficiency) and muckpile profile (another indicator of blasting effectiveness). Figures 4 and 5 are digital ground models before and after a quarry blast. The original volume was 9,728 cubic meters. After blasting, the volume of the muckpile was 13,240 cubic meters, representing a 36 percent swell.

These models were produced by establishing a traverse around the blast area and collecting data from each station in the traverse. The back line of the blast was measured using a target to clearly define the area to be blasted. If the operator wanted to have exactly the same coordinates for both models, the easiest technique would be to set up the first station for each model on the same point and backsight the same point before starting measurements.

Figure 6 shows a detailed profile drawn through a muckpile (generated from a digital ground model). This type of profiling can be used to compare muckpile profiles and blasting results as blasting parameters are changed (e.g. changes in explosive type and loading, pattern, hole size, etc.). It also gives an excellent indication of casting efficiency.

Although the models in Figures 4 and 5 are produced from a quarry blast, it also applies to construction blasting. As an example, road cuts for highway work can be accurately and quickly modeled to determine actual quantities blasted, theoretical quantities (based on existing ground conditions and neat lines) and the amount of overbreak. The author's experience indicates that this is a more accurate technique compared to traditional cross sectioning, particularly in rough ground conditions.

Another common application involving quantities is for inventory control. Figure 7 shows a model of a stockpile generated from laser data. The techniques used have been proven to be very accurate - comparison of quantities measured by use of a laser system to other techniques consistently show the results are within 1% of actual values, provided the field work is done carefully and correctly.

4.3 Mapping Applications

One of the best applications for reflectorless lasers is for gathering data to produce maps and plans of quarry and mine operations. Because there is no need for someone to physically occupy the position being measured, it becomes easy to measure to many areas that are inaccessible to regular survey techniques, such as rock crests and toes and fault lines.

Figure 8 shows a part of a quarry operation that was mapped using laser technology. Because it is necessary to update these types of plans, proper survey control (with a number of known stations) must be established. The types of detail that can be shown include:

- -Progression of rock faces over time
- -Limits of stripping, and quantities of exposed rock available
- -Quantities of rock removed over time (by blast, by year, by area, etc.)
- -Accurate face heights
- -Geological features
- -Physical features, such as crushers, belts, roads, etc.

The drawings generated within CAD packages are scaleable, allowing for quick calculations. The base data is generated by setting out a series of control stations around the area and measuring all the details from each of those stations. If extra detail is required, the re-sectioning method can be used. One of the major advantages of this application is that updates are easy to do. Once survey control is established, all data is collected and the overall plan is generated, only the areas that have changed need to be updated. This makes the process much cheaper than having aerial photography done at regular intervals.

Figure 9 shows how laser mapping combined with quantity calculations can be used to plan production blasts and control quantities. In rough terrain, the operator quickly knows how much rock is available from each blast and what the effect of changing blasting parameters would be on production rates.

4.4 Drilling Control

In rough areas, the laser can be a very useful tool for laying out and controlling drilling depths. Figure 10 shows a small section of a quarry where very rough ground, existing muckpiles and quality control requirements makes it hard for the operator to control drilling depths. In combination with mapping, drill holes are located and shot with a laser system, and the required drilling is calculated and given to the driller, as shown in Figure 11. Better control of drilling depths can reduce vibration problems, improve fragmentation and better control the final quarry or mine floor.

4.5 Tunneling Applications

Lasers can be used for profiling tunnels - either under construction or in operation. Figure 12 shows a typical tunnel profile in a blasting operation. This type of information can be used for many purposes, including:

- -Quality control on new construction
- -Overbreak quantities (important for payment purposes and when the overbreak has to be replaced with concrete)
- -Clearance measurements for existing and new tunnels

5.0 Summary

There are a number of applications for lasers related to blasting that have not been covered in this paper. Examples include short and long term slope stability monitoring, underground volumetric measurements (of stopes, voids and cavities) and cast blasting efficiencies. In the longer term, lasers may be used to directly measure face velocities in blasting, position and control drill rigs, measure to geological features directly and accurately measure shipping volumes (to replace the weight scale). The purpose of this paper was just to give a brief overview of what can be done with lasers in the blasting and excavation field. At the moment the major restriction is not with the hardware but instead is the software. This is an area that will see a lot of changes over the next few years, resulting in improved blast design and control.

Acknowledgments

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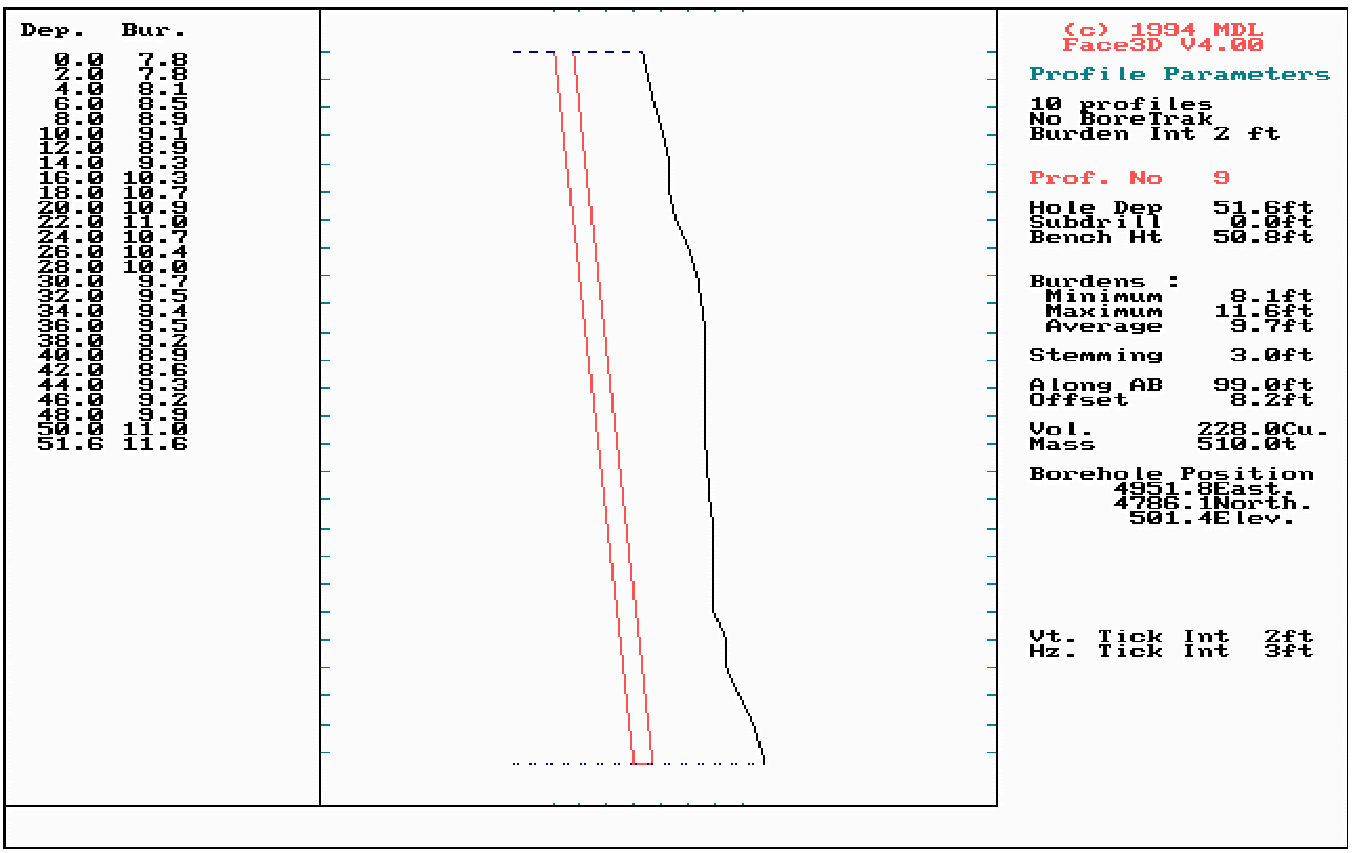

Figure 1 - Face profile in front of an angled hole showing consistent burden

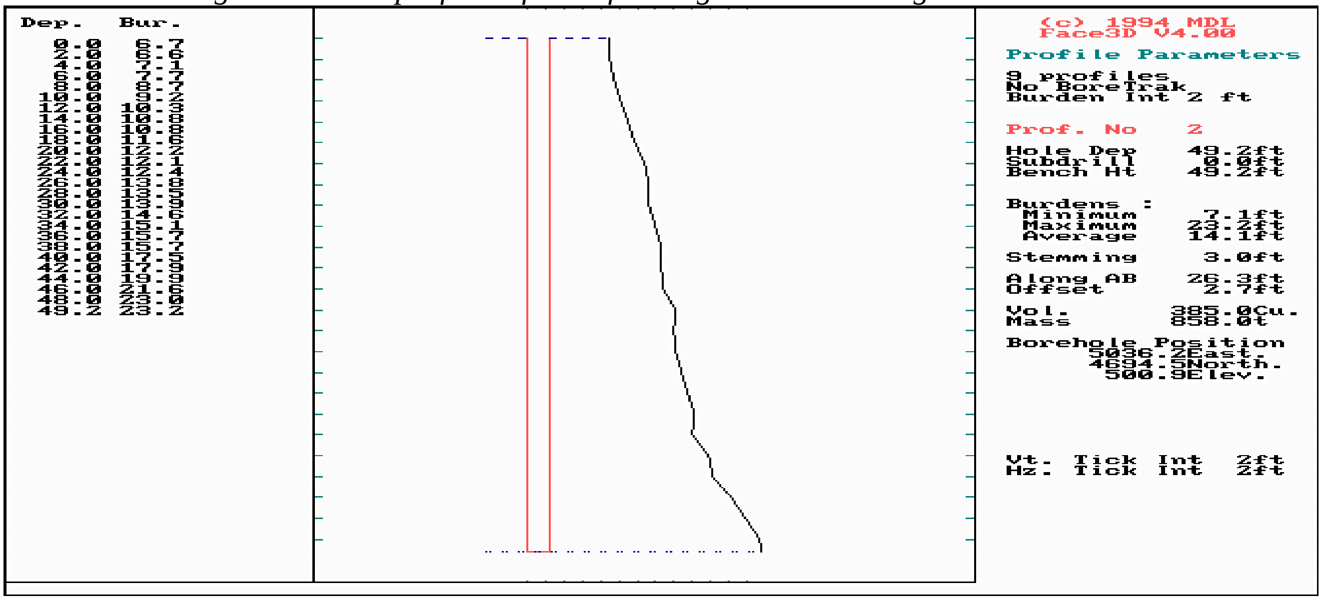

Figure 2 - Face profile in front of a vertical hole, showing excessive toe burdens (potential vibration, oversize fragmentation and tight digging problems) and possible flyrock and airblast problems from the top section of the blast.

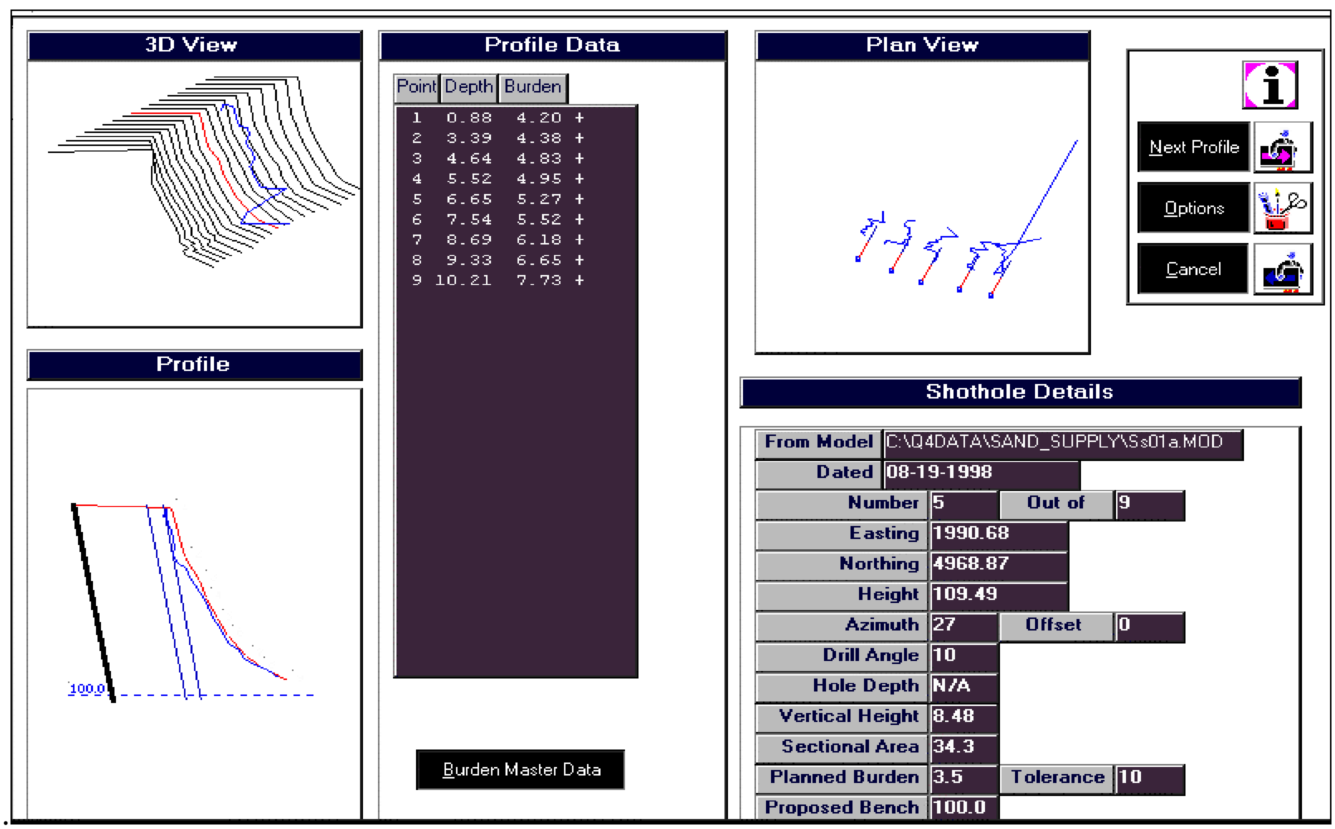

Figure 3 - Example of minimum burden occurring at locations not in directly in front of the borehole (Calculated by MDL Quarry.4 software)

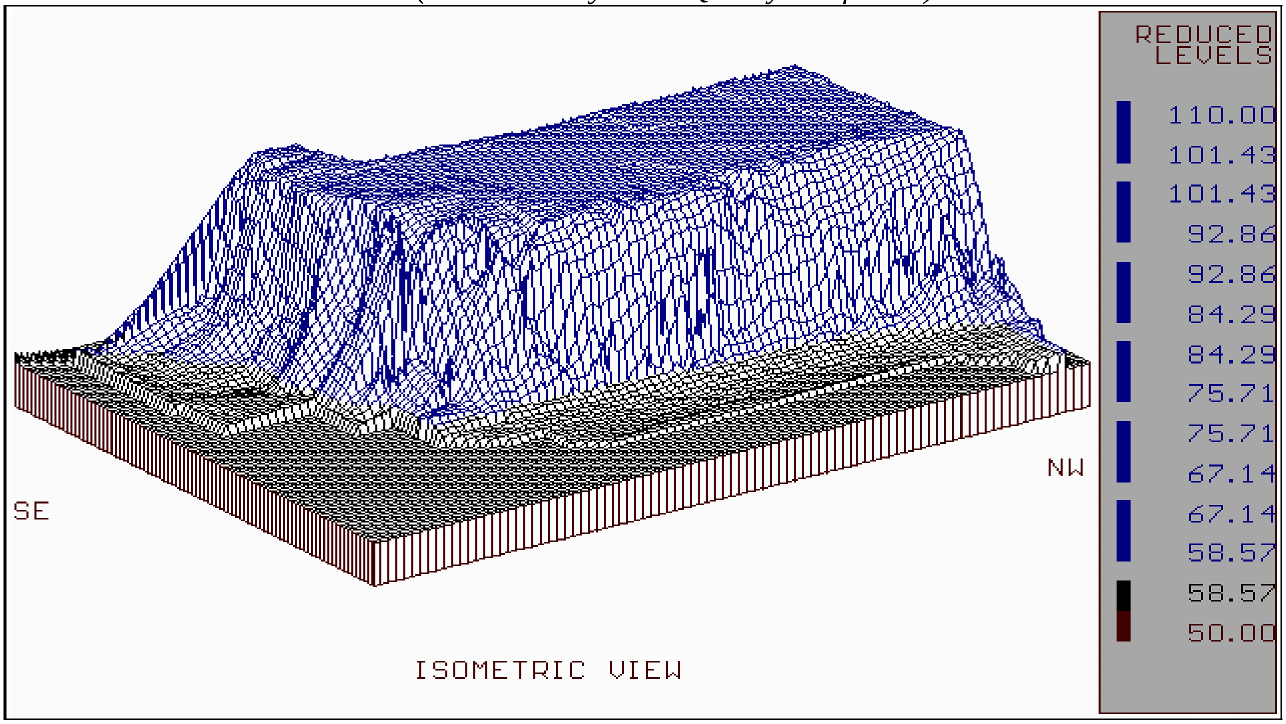

Figure 4 - Ground model of area to be blasted

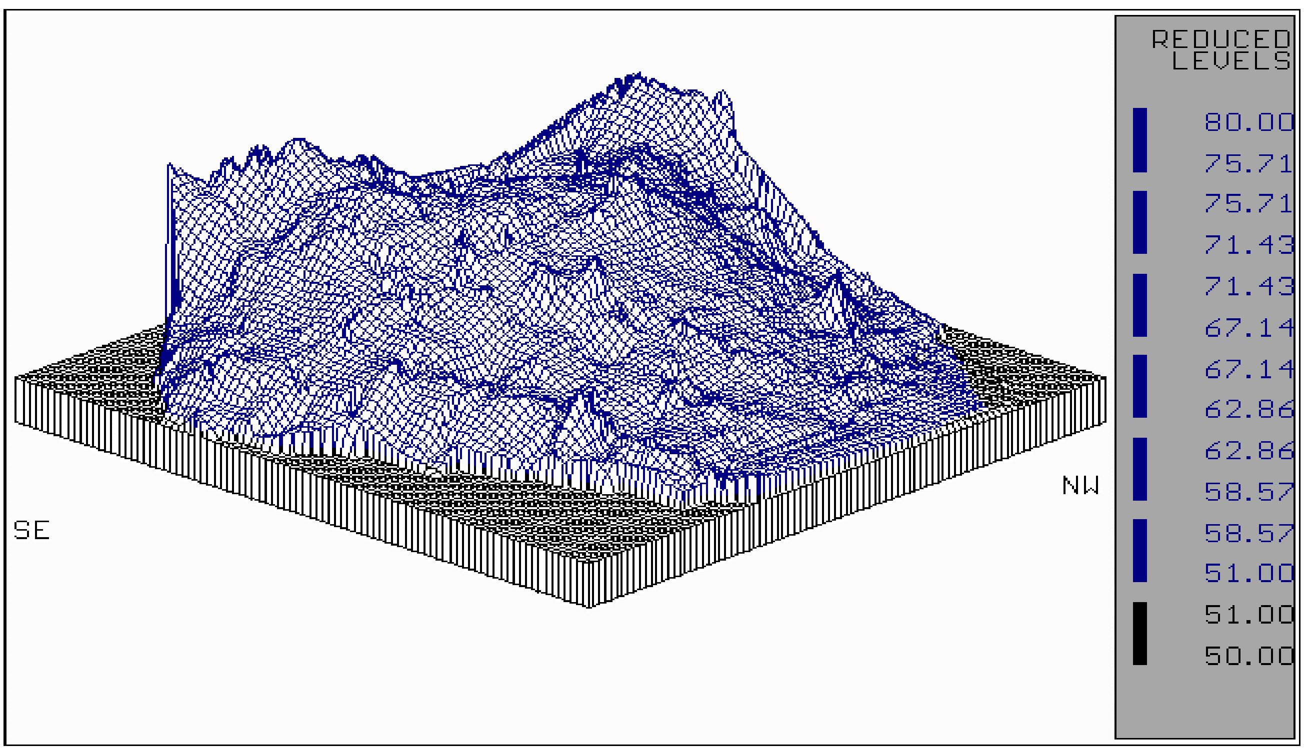

Figure 5 - Ground model of muckpile from the blast

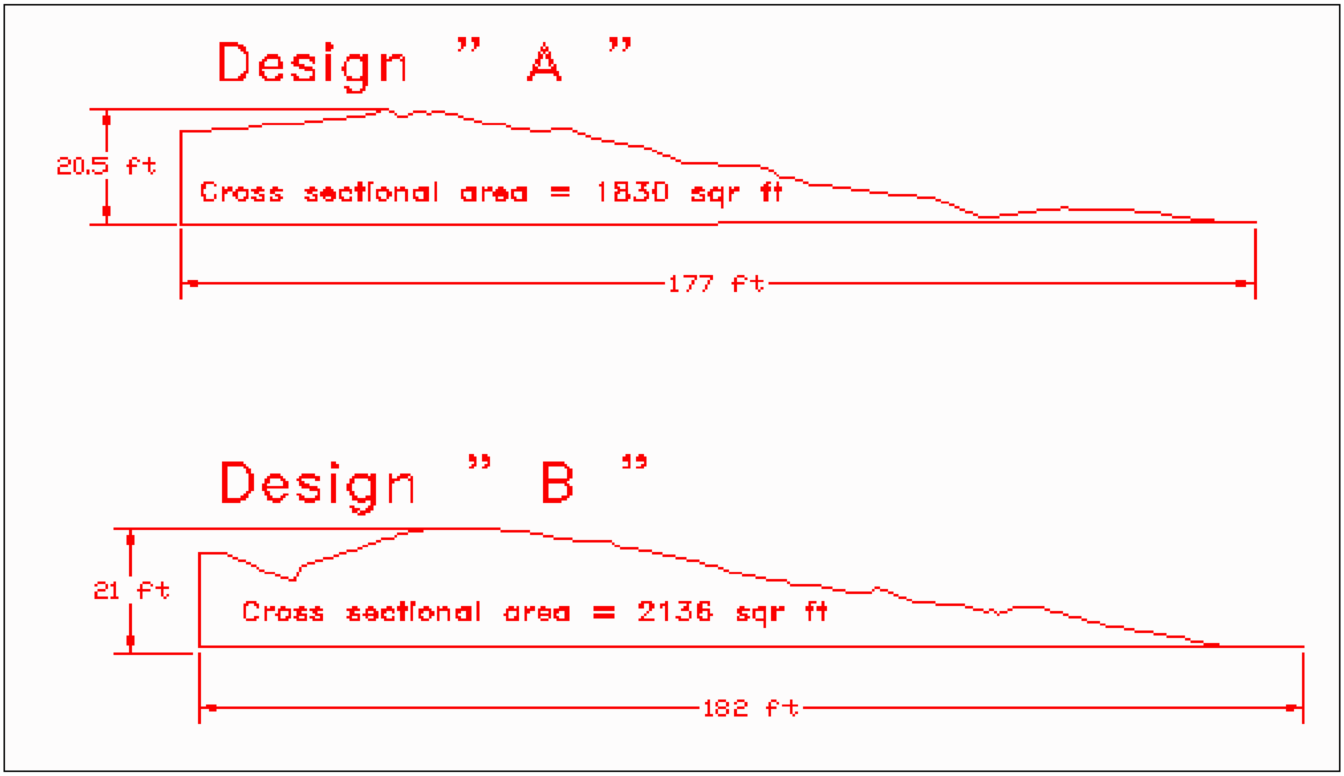

Figure 6 - Profile through a muckpile showing height, cross sectional area and distance of throw

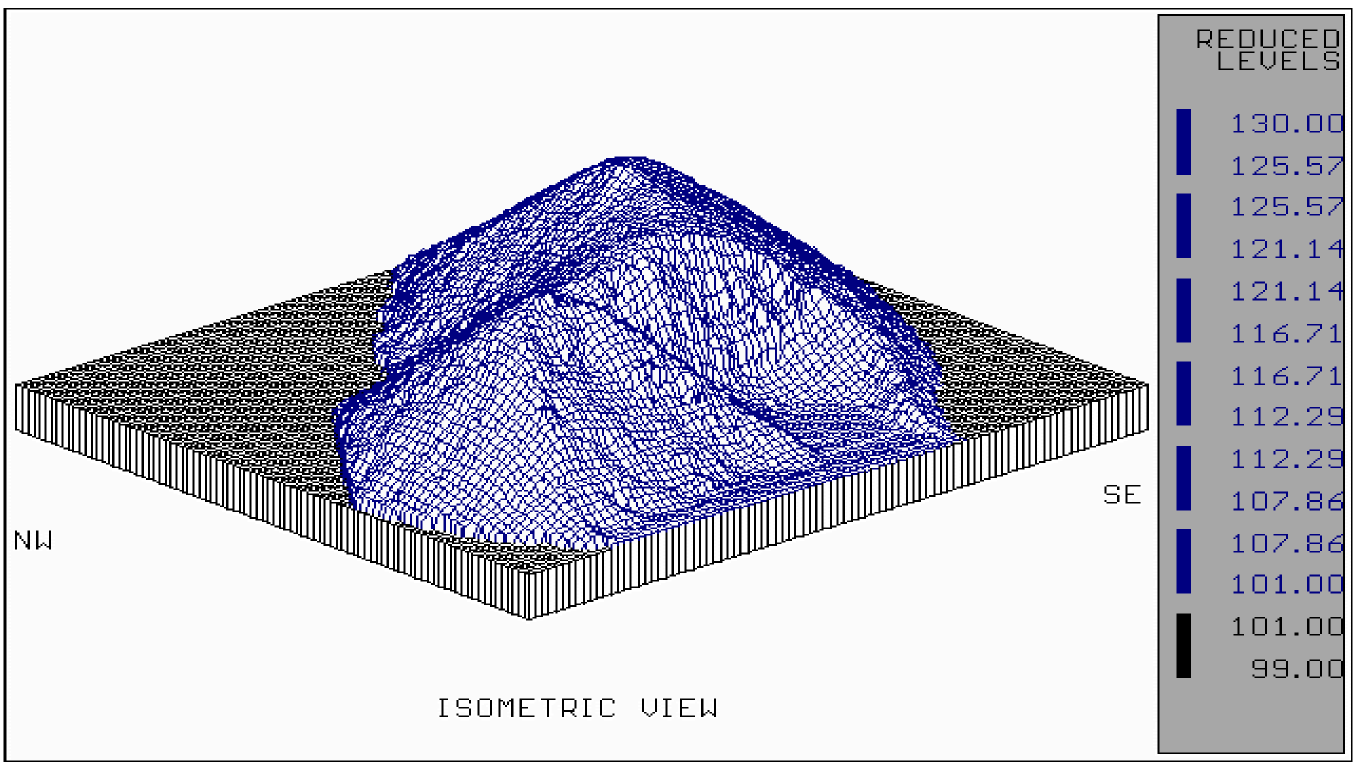

Figure 7 - Typical stockpile measured with a reflectorless laser system

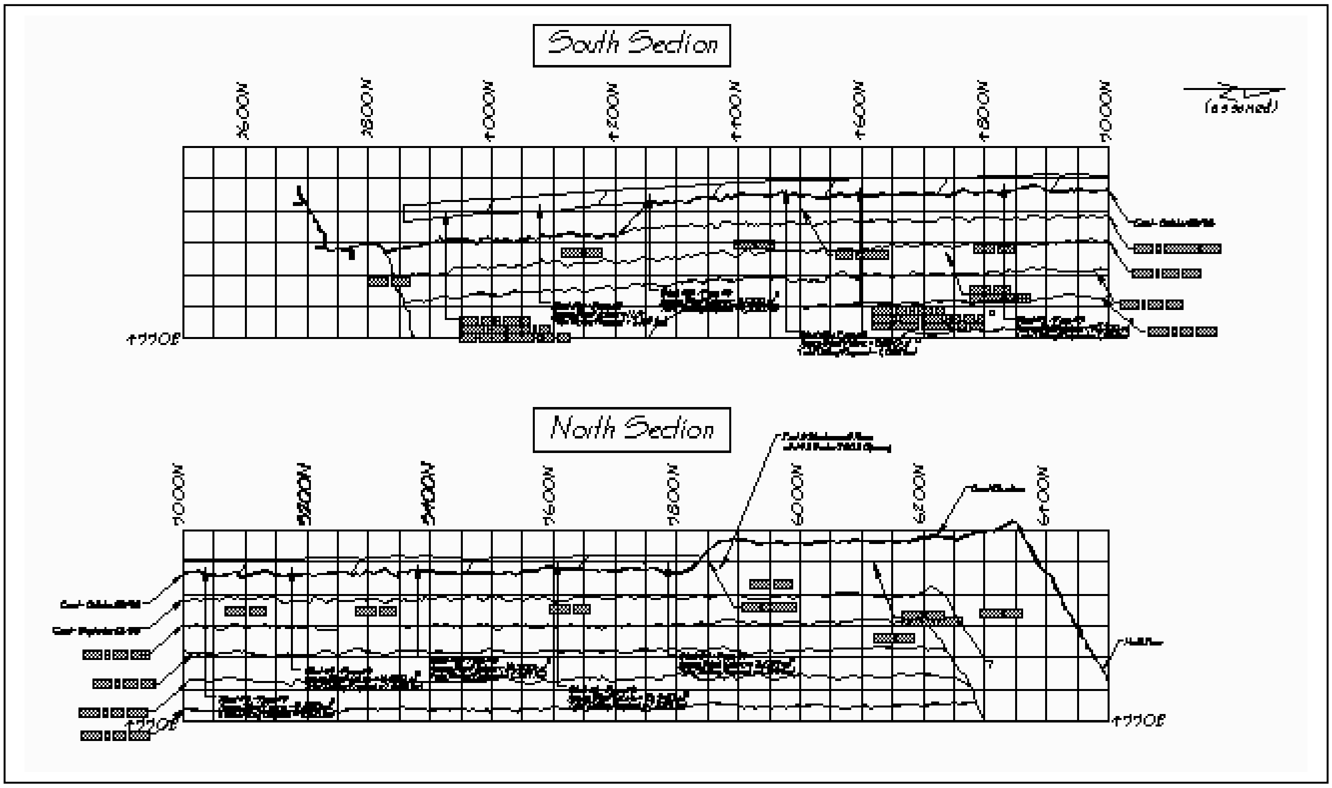

Figure 8 - Quarry Plan showing individual blast layouts

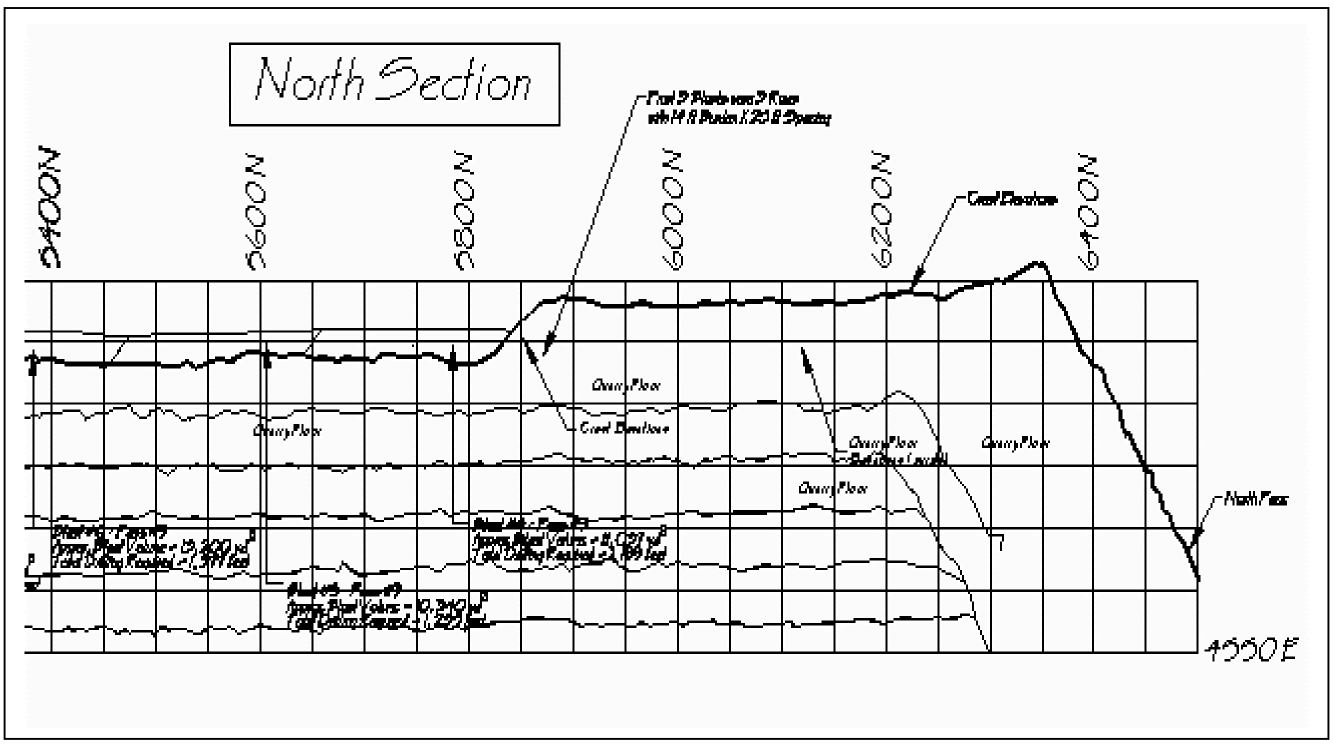

Figure 9 - Partial Quarry Plan showing individual blast layouts and quantities

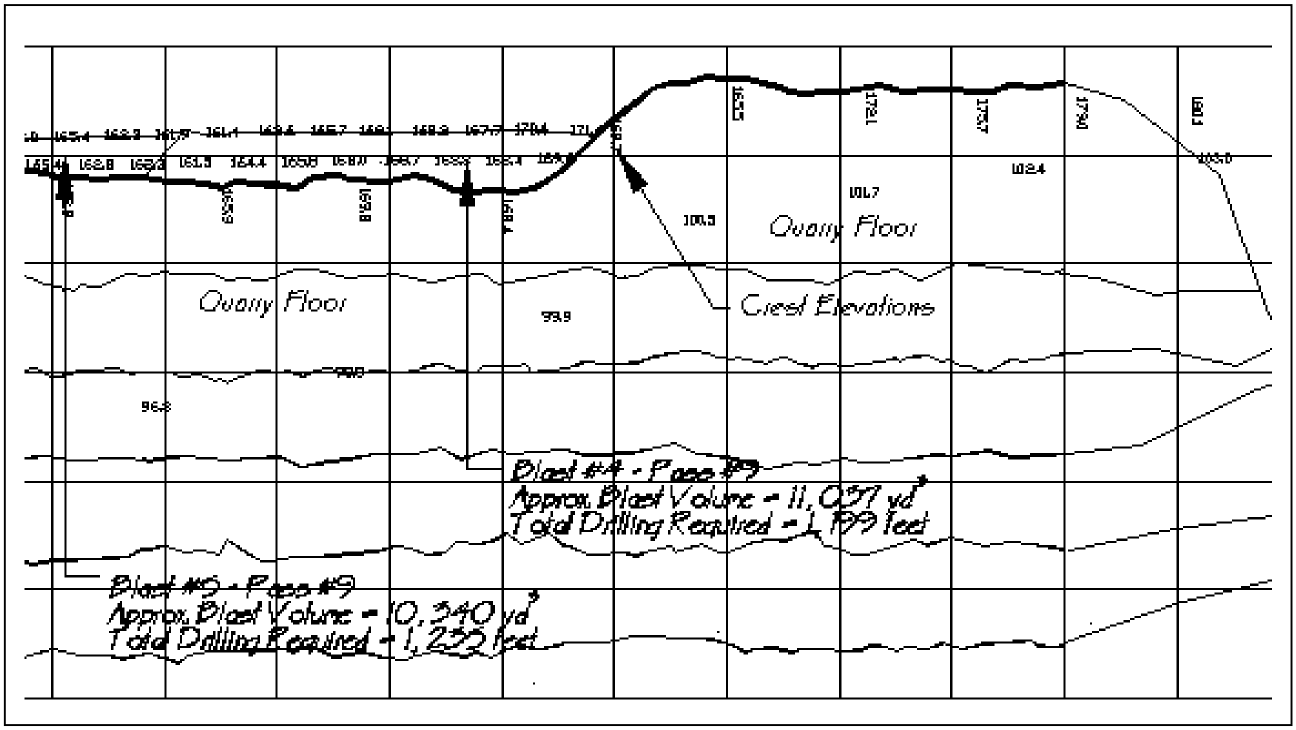

Figure 10 - Partial Plan showing drill holes located with a laser system

Drilling-Blasting Report

ABC - North Quarry

Survey Date: Aug 6, 1998

Blast #1 - Pass # 5 - North Face (Spacing 14' X 23')

Hole#	Row	Top of B/H Elev.(ft.)	Toe of B/H Elev.(ft.)	Sub Drill (ft.)	Drilling Required (ft.)
1	A	185.10	100	6	91
2	A	183.30	100	6	89
3	A	181.50	100	6	88
4	A	181.60	100	6	88
5	A	180.60	100	6	87
6	A	178.10	100	6	84
7	A	176.00	100	6	82
8	A	173.80	100	6	80
9	A	173.00	100	6	79
1	B	185.90	100	6	92
2	B	185.20	100	6	91
3	B	181.90	100	6	88
4	B	182.70	100	6	89
5	B	181.40	100	6	87
6	B	179.20	100	6	85
7	B	176.40	100	6	82
8	B	174.00	100	6	80
9	B	173.50	100	6	80
1	C	187.10	100	6	93
2	C	184.40	100	6	90
3	C	183.20	100	6	89
4	C	182.50	100	6	89
5	C	179.90	100	6	86
6	C	177.30	100	6	83
7	C	174.20	100	6	80
8	C	174.20	100	6	80

Estimated Volume of Rock (yd³)	n/a
Total Drilling Required (ft.)	2232

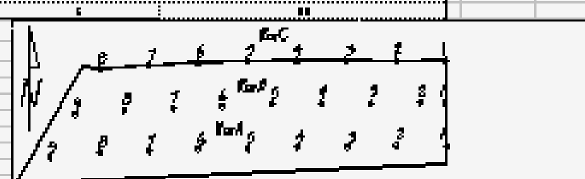

Figure 11 - Drilling Layout Sheets for Use by the Driller

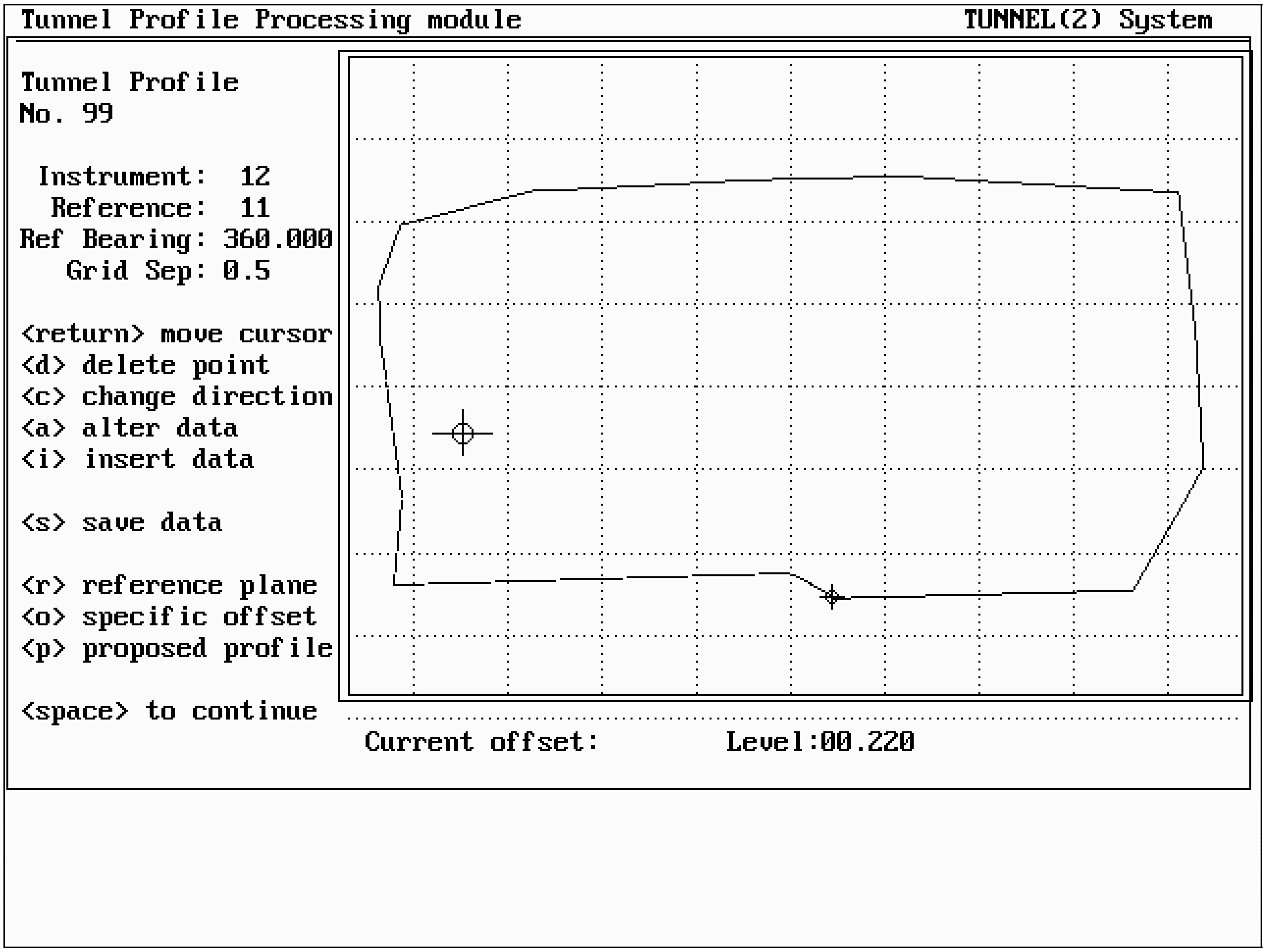

Figure 12 - Typical Tunnel Profile