Resolution of Some Common Problems in Highway Blasting

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In this paper is presented a description of several problems associated with highway blasting that continue to recur with undesirable results. Suggestions are offered for handling such problems so as to mitigate or eliminate their impacts on future projects. The problems discussed involve selected aspects of presplitting of slopes, oversized rock in required excavations or quarries, design and excavation of benches, blast effects, and seismic data processing. The suggested solutions require a better understanding of geology, rock mechanics, and seismology and involve all parties to the work—designers, specification writers, explosives users, and those who monitor blasting effects. The examples selected for discussion reflect actual experiences on real projects. However, neither the projects nor the individuals involved are identified by name.

Many persons involved in highway design and construction share a common desire to achieve optimum results whenever explosives must be used for rock excavation. It is also perceived that there are different incentives that affect the design and execution of the work. The most cautious and precise work with explosives is the most expensive. Designers may wish to have the best possible results, but contractors may wish to accomplish the work in the fastest and least expensive manner. To achieve a balance among time, cost, and physical result for the specific needs of a particular project, designers must understand field conditions and blasting procedures to a degree that permits realistic designs. Because of the many possible choices in the degree of caution and precision required in the work, which directly affects the time and cost of the work, specification writers must correctly convey to bidders what must be accomplished without a conflict between methods and limits. Contractors must have an understanding of the field conditions and the skills needed to accomplish the work. Those who monitor the work must have sufficient experience to make a proper evaluation and to predict the outcome and consequences of ongoing work. All parties should understand the specific needs of the project in question because these needs are not necessarily the same as those of past projects that might appear to be of similar character.

It would be easier to accomplish these goals if all field conditions were the same. This would permit the use of standardized specifications and field procedures that could be expected to produce uniformly satisfactory results. Unfortunately, that is not the case. A procedure that works well at one site may produce highly unsatisfactory results at another site. This means simply that the use of explosives is a site-specific technical art not an exact science. The following discussion is intended to help readers put into perspective some of the more commonly faced situations that may generate unsatisfactory results, as well as to offer one or more possible solutions for each.

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PRESPLITTING OF SLOPES

There are several techniques by which explosives users attempt to produce smooth, sound, final slopes along the perimeters of rock excavations. One of the most commonly used methods is known as presplitting or preshearing. This is a method of generating a crack in the rock along the desired limit of breakage in advance of the pattern blasting. Presplitting defines the limit of the excavation, and pattern blasting brings about the fragmentation of the rock to be excavated. The two are usually part of the same detonation sequence, with the perimeter holes detonating first followed by the detonation of the pattern holes. The perimeter holes are loaded with special charges that are smaller in diameter than the borehole. The annular ring of air between the charge and the borehole wall provides a decoupling of the energy. This decoupling reduces the shattering effect on the borehole wall but transmits enough energy to develop a crack between the holes by means of tensile stresses in the rock web between the holes *(1,2)*. To predict presplit vibrations, see Figure 1 and the section on data processing.

During the 1950s and 1960s, this technique gained broad acceptance in the industry and became increasingly required by contract specifications for the final surfaces of many structural excavations and for many highway cut slopes in rock.

Unfortunately, there is one aspect of this type of blasting that is often overlooked by specification writers. That is the need for a very large "burden" of rock (the dimension between the explosive and the free face) in front of the final slope. This need becomes even more critical if the presplit holes are detonated as a separate blast. When the presplit holes are detonated, explosive gases are generated and there is a very high pressure against the section of rock in the cut area. On a through-cut in a wide hill, sufficient burden usually exists to resist this pressure, and the desired crack can be generated without shifting the hillside. However, for a side-hill cut, the results can be disastrous if there is sufficient pressure to displace the cut section.

On a side-hill cut in the state of Washington, specifications required that presplitting be done as a separate operation ahead of production blasting. The first presplit blast caused the entire cut section to be displaced outward about 18 in. This displacement was accompanied by a prominent loosening of the rock so that it could not be drilled with the track drills that the contractor had on the project. It was a technical and financial disaster for the contractor (Figure 2).

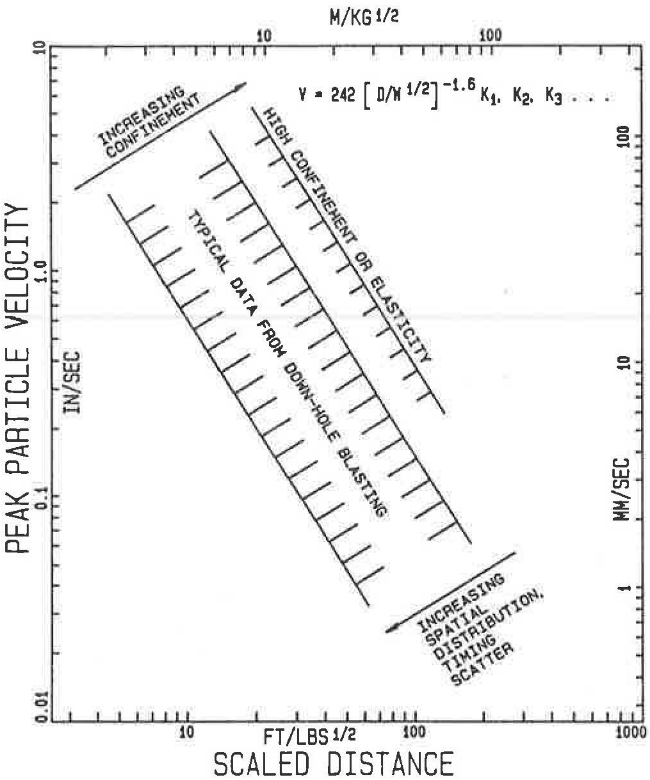

FIGURE 1 Prediction curves for ground vibrations caused by blasting.

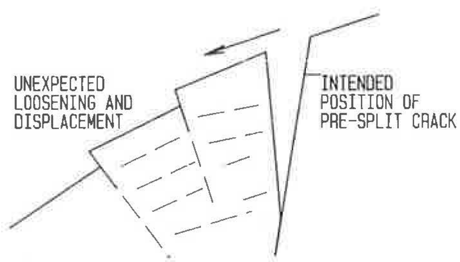

FIGURE 2 Side-hill cut displaced by presplitting.

On a major project in British Columbia, a presplit blast was detonated on the downhill side of a large through-cut. Although it was 75 ft to the outside face of the hillside, a section of rock 300 ft long by 75 ft wide by 20 ft high was shifted outward and uphill by at least 1.0 ft. Concrete was to be placed against a portion of this rock face, and the rock displacement was a serious problem for the completion of the design.

On a small side-hill cut in a southern state, an effort was made to combine presplitting with pattern blasting in a single detonation. However, the rock shifted so badly during the presplitting that some of the pattern holes were cut off, leaving undetonated explosives in the badly loosened but poorly fractured muck. An accidental detonation occurred later.

The solution to this problem is readily available. If there is any doubt about the success of this technique, because of limited dimensions of rock burden, presplitting should be replaced with an alternative technique called "smooth blasting" or "cushion blasting." In the latter technique, the perimeter holes are loaded much as they are for presplitting, but the charges are detonated last instead of first in the firing sequence. Smooth blasting minimizes the danger of displacing the rock mass until each successive portion has been fragmented during the planned blasting sequence.

It is possible, also, to lessen the tendency of presplitting to displace rock by introducing more delays into the blast. Theoretical considerations suggest that it is necessary to detonate all presplit holes simultaneously, and it is thought by many that such a procedure must be followed in order to develop the desired crack along the rock perimeter. Field experience demonstrates that this is not necessary. It is acceptable to detonate as few as several holes per delay, thereby slowing down the action of the explosive gases against the rock section and lessening the chances of displacement.

It is possible that the first two of the three disasters mentioned could have been prevented by a judicious design of presplitting patterns using only several holes per delay, if the detonation times had been sufficiently spread out in time. However, the third could not have been prevented as long as presplitting techniques were used. Longer time intervals would only have made the problem worse, permitting more time for the rock to shift. Burden dimensions were too small.

Engineers are sometimes encouraged for aesthetic reasons not to require controlled perimeter blasting on highway projects. Such blasting produces a smooth, linear perimeter. Some persons prefer the more "natural" look achieved if there is no control of the perimeter excavation, in which case a more ragged rock profile is produced. Whichever choice is made, it should be done with the recognition that uncontrolled perimeter blasting leaves a rock slope in a loosened condition that will generate more falling or raveling rock and require a higher level of long-term maintenance. Because of this, increasing use is being made of perimeter control even on projects that do not involve public safety, such as open-pit mines. These procedures provide greater stability to mine slopes and reduce maintenance costs.

OVERSIZED ROCK IN REQUIRED EXCAVATIONS OR QUARRIES

Many highway projects have encountered serious problems with oversized rock, whether from grade excavation or from borrow areas supplying rock products for the project.

There have been many "rules of thumb" developed over the years to guide explosives users, and many of these have been developed specifically to bring about the optimum fragmentation of the rock being blasted. In general, these are not founded on theoretical considerations but are the consensus of opinion of experienced users for average or typical field conditions. They can be quite valuable for inexperienced users and may prevent disasters, especially those associated with such safety considerations as flyrock. However, most of the rules of thumb were developed for midwestern quarries in highly jointed limestone or similar sedimentary types of rock. If these rules are followed for that type of setting in relatively uniform rock, the explosives user can expect good fragmentation. Unfortunately, the results would not be as good in other settings.

Perhaps the most important contribution that can be made to the subject of rock fragmentation is to develop an understanding of the manner in which the fragmentation is controlled by the specific characteristics of the site in question. The question is not to develop a rule for blasting but to develop an understanding of rock characteristics so that the explosives user can refine his field procedures to achieve the optimum fragmentation for the site and project in question. The word "optimum" is used to describe the best results that can reasonably be achieved within the cost and time constraints of the project. The demands of one project may require fine fragmentation regardless of cost. The demands of another may permit hauling of oversized rock to waste sites at less cost.

As has been implied, problems with oversized rock in the excavation of highway cuts, or in quarries used to supply rock products for highway construction, are strongly related to the geology of the site in question and hence regional in character. There are several commonly encountered geological settings that contribute to the production of oversized rock. One of these is a setting characterized by a hard cap rock overlying softer rock or separated from the underlying material. An example in sedimentary rock might be a hard dolomite or sandstone over soft shale. In volcanic rock, an example might be a hard basalt overlying an interflow zone of clay or ash.

In such settings, it is difficult to break the cap rock unless it is naturally composed of highly jointed rock that will break readily into smaller particles. With ordinary blasting methods, explosive energy is expended in the soft zones (the path of least resistance) and does little to damage the overlying hard cap rock. After blasting, the cap rock may be found as huge slabs or blocks of unbroken rock mixed with pulverized particles of the underlying material. Usually, the oversized rock must be sorted and stockpiled for later secondary drilling and blasting—a very expensive process.

There is a normal tendency to reduce the time and cost of blasting operations by designing blasts for larger-diameter blastholes widely spaced. Under the field conditions described, such a procedure would exacerbate the problem of oversized blocks. The situation is improved by drilling more holes of smaller diameter so as to distribute the explosives into a greater number of smaller charges. Also, the less concentrated charges can safely be placed closer to the ground surface to break the cap rock. In more severe cases, it is necessary to place separate, small charges in the upper parts of the holes (called "deck" or "decked" charges) or to add short satellite holes to provide even more charges in the cap rock, or both. Satellite holes are placed between the deeper pattern holes to provide an overall pattern of closer spacing (Figure 3).

In igneous rock, an example of oversize problems would be those sometimes found in certain weathered granites. One illustration is found in a project near the continental divide in Montana, where a contractor was forced into bankruptcy because of problems in excavating a long, deep through-cut

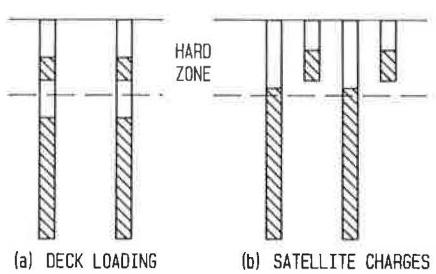

FIGURE 3 Methods of fragmenting hard cap rock.

through weathered granite. Because of low velocities measured during seismic refraction studies, it was thought that the rock could be excavated without blasting. And, indeed, it was possible to excavate without blasting. However, the material proved to be large residual remnants of weathering ("core stones") embedded in decomposed granite of the consistency of a coarse sand. At the time of primary drilling and blasting, it was impossible to locate the positions and sizes of the individual boulders so that explosive charges could be placed in each. The contractor was forced to drill and blast each one individually after initial excavation. The cost was unbearable and forced the contractor into bankruptcy.

In granitic rock, it is common to find exfoliation jointing, a process of stress relief that causes separation of rock in layers parallel to the exposed rock surfaces, which may be strongly curved in many instances. This condition exhibits many of the characteristics of the cap rock described previously, but it is usually a more serious problem. The cap is often composed of very hard rock and joints may be 20 ft or more apart laterally. Further, it may be difficult to locate the curved exfoliation joints with sufficient accuracy to avoid placing explosives in the open joints when placing explosives in the hard blocks where they are needed.

Lateral variations are often found in the weathering profiles of granites, giving an unpleasant combination of cap rock and core stones. Thus, oversized blocks may be found at any location in the rock mass.

For massive rock with tight joints, it may suffice merely to increase the powder factor. It has been well proved that an increase in the amount of explosive energy does improve fragmentation. However, in cases in which the rock is highly heterogeneous, or characterized by open joints, merely increasing the powder factor is not enough. It will be necessary, also, to introduce a larger number of smaller separate charges into more portions of the rock in order to break up more of the individual blocks. In extreme cases, such as the Montana project cited earlier, the least expensive alternative is to use secondary blasting methods or haul the oversized rock to waste sites.

In cases in which most of the oversized rock comes from the top portion (stemming zone) and the face zone of each blast, it may be helpful to increase the depth and width of each blast so that these zones become smaller percentages of the zone being blasted.

Unfortunately, there is no simple adjustment of blasting techniques that solves this problem without incurring some additional costs. Therefore, it is essential that bidders for rock excavation work involving explosives have a reasonably accurate understanding of the rock type and its characteristics. Whether that understanding is developed through information provided by the project owner or obtained by the bidders, it is an essential part of the process. It is not sufficient merely to understand how to blast once the condition is revealed. Bidders must understand the field conditions, then plan the choice of equipment and blasting methods accordingly. More information about blasting products and blast designs is contained in various blasters' handbooks and references such as Dick et al. *(3)*, as well as the selected publications noted in its bibliography.

BENCHES

A number of questions can arise concerning the excavation of benches in rock. Some of these concern the sizes and locations of the benches; some concern the methods of accomplishing the excavation.

The most common reason for excavating benches in highway cuts in rock is to improve safety. Many states have standardized rules for the width of benches and the vertical distance between benches. Unfortunately, these rules rarely include any consideration of the jointing or bedding characteristics of the rock. It is presumed that an excavated bench will be a horizontal ledge of stipulated dimension and that it will catch any loose rocks that roll down the slope, thus preventing them from striking passing vehicles or falling onto the road surface to become traffic hazards.

With appropriate blasting techniques, it is possible to achieve a reasonable approximation of this idealized picture in certain geological settings, such as those characterized by horizontally bedded sedimentary rock of good quality with well-developed horizontal joints or partings. Unfortunately, however, the addition of benches only increases the hazards in other settings. If similar rock is characterized by open, outward-dipping joints, it will be impossible to excavate horizontal benches. Wedges of rock will slide out. The benches will slope downward and outward. Not only will they be incapable of catching stones, they will deflect them farther outward toward traffic lanes than would be the case if the benches did not exist.

Small, narrow benches are rare in nature. In most rock types, bench corners tend to be unstable and will provide loose stones to roll down the slope. On the other hand, an absence of benches permits falling stones to gain great speed and momentum, thus increasing their potential for damage. It appears that a reasonable compromise must take into account the specific characteristics of the slope in question. When these characteristics are unknown, it is better to design wider benches at greater intervals than narrower benches at closer intervals. The wider the bench, the more chance there is that at least some portion of it (the inner portion) can be excavated horizontally or even slanted inward. This would improve the ability of the bench to catch falling stones (Figure 4).

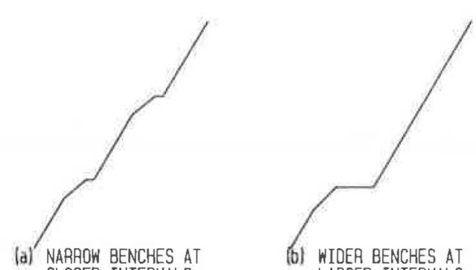

FIGURE 4 Alternative bench designs.

A case history is provided by a paved access road along a steep canyon wall leading to a dam and hydroelectric plant in one of the northwestern states. Modifications required widening of the road, and state specifications required certain horizontal and vertical limitations on benches. Because of overall limitations on available space, conformance to these specifications would have generated a hazardous situation, providing an outward sloping bench to project stones onto the road while severely restricting the dimensions of the drainage ditch and shoulder on the inside of the road. The final solution involved eliminating the bench on the canyon wall and using that space for a wide shoulder and drainage ditch at the road level. Although the solution required a departure from standard procedures, it provided a much safer condition.

Square bench corners are rarely found in nature. Further, they are difficult to develop by blasting. The normal response of rock to blasting causes the loss of bench corners because of the natural upward block motion effects of the blast (cratering), which are caused by the combined effects of tensile slabbing and gas venting and the tearing effects of adjacent rock movement.

There are certain blasting techniques that can be used to improve the chances of preserving the corners of rock benches. However, such techniques must be designed to overcome or modify the normal site responses mentioned previously. The term "modified site response blasting" is used to describe these techniques. For example, if the rock in question is such that the explosives user finds it impossible to preserve bench corners with the normal sequence of drilling and blasting, this response may be modified on some projects by holding the rock in a confined condition while light charges are detonated along the planned lines of breakage. Holding the rock in a confined condition modifies its normal response and may permit the work to be done. If several "lifts" (consecutive benches of blasting) are required, it is sometimes possible to drill and blast a bench corner while an overlying burden remains on top of it to hold it in place. Drilling and blasting are done "in the blind." Even here, however, the precise sequence of drilling, blasting, and excavating activities is crucial to the success of the method. Because these must be custom designed for the specific characteristics of the site, it is difficult to offer generalized recommendations. Further discussion of these techniques can be found elsewhere *(4)*. This reference work describes complex structural excavations using these techniques.

BLAST EFFECTS ON HIGHWAY FACILITIES

Along cross-country highways, there are usually relatively few structures and facilities that have any susceptibility to damage from blast effects. Of course, when these highways enter urban areas, or pass nearby, it is necessary to take into account the myriad questions of public response, residential structures, and other facilities that may not be found in outlying areas.

The main incentive for commenting on this topic in this paper is that there are still many cases in which the blasting limitations for structures of high strength are as restrictive as they might be for residences. Although this situation does not in any way represent a hazard, it sometimes represents extreme increases in cost and time for the completion of the work. A case in point is that of a large highway rock cut passing over a concrete-lined tunnel in one of the northern states. The highway department of the state in question had thought originally that the rock was sufficiently weathered that it could be excavated without blasting. Unfortunately, this turned out to be an incorrect assessment of the rock. After the work was well under way, it was discovered that blasting would be required. Work was halted for about 2 years while the interested parties debated the restrictions for blast effects on the tunnel and obtained the required insurance. Enormous additional costs were incurred because of unnecessary concerns about the tunnel.

In particular, there were two aspects of the requirements that were unnecessarily conservative. One was the vibration limit of 2.0 in./sec for a concrete-lined rock tunnel. Such a limit is more appropriate for residences. The second requirement called for an insurance policy that would cover damage for 5 years after the completion of the work. This requirement was based on the false premise that vibration damage might not be disclosed at the time of occurrence under these field conditions.

There is ample field experience with ground vibration effects on concrete-lined and unlined underground openings in the range of 20 to 200 in./sec to indicate that the lower particle velocity limits often applied to residences are unnecessarily conservative for these tunnels. Understandably, there is no single number that fits all circumstances, but it is usually conservative to consider limits at least as high as 10 in./sec. In some instances, far higher values may be acceptable. For comparison, Tennessee Valley Authority (TVA) specifications call for vibration limits on concrete in the range of 10 to 20 in./sec, discussed later [Table 1, Figure 5, (*2; 5; 6*, p. 256; *7; 8*)].

As a general policy, there is no need to allow higher limits than those that do not pose any additional costs or delays to the work. However, if this approach leads to extremely low particle velocities, future readers may believe mistakenly that such numbers represent the maximum allowable vibration rather

TABLE 1 TVA BLAST DAMAGE CRITERIA FOR MASS CONCRETE

Concrete Age from Batching	Allowable Particle Velocity from Blast-Induced Vibrations (ips)[a]
0 to 4 hr	4 × DF[b]
4 hr to 1 day	6 × DF
1 to 3 days	9 × DF
3 to 7 days	12 × DF
7 to 10 days	15 × DF
10 days or more	20 × DF

[a]1.0 in./sec = 2.54 cm/sec.
[b]DF = Distance factor, defined as

DF	Distance from Blast to Concrete [ft (m)]
1.0	0–50 (0–15)
0.8	50–150 (15–46)
0.7	150–250 (46–76)
0.6	Greater than 250 (76)

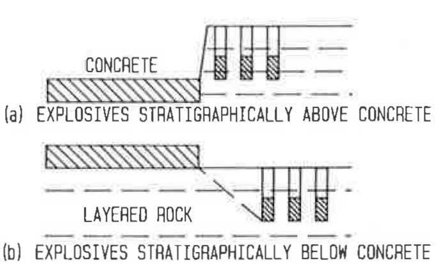

FIGURE 5 Stratigraphic position of blasting.

than a convenient, nonrestrictive limit. It is this type of misinterpretation that leads gradually to more and more restrictive limits, regardless of need.

It is, unfortunately, a common belief that any manner of vibration damage may reveal itself long after the event, even years later. Except for a few rare types of occurrences, that is not true. The contrary is usually true. One diagnostic characteristic of vibration damage to a lined tunnel would be its immediate appearance. This would also be true of the superstructures of bridges. Highway slabs, per se, are not susceptible to damage from elastic blasting vibrations outside the zone of block motion. However, a blanket statement cannot be made about slab foundations, such as those resting on embankments.

One approach to writing specifications that attempts to distinguish among the different mechanisms by which damage may occur is that of writing one portion of the specifications to cover simple particle velocity limits and another portion to cover the potential for block motion, that is, the shifting of ground supporting a slab or a structure. Since 1976 the TVA has used this type of specification, written by this author. It has been reported that no damage has occurred within the limits of this specification, although it appears to be far more liberal than most. The limitations are directly related to the age of the concrete and indirectly related to frequency by distance relationships. For example, for low-profile mass concrete, such as footings, slabs, and the like, with an age of 10 days or more, the allowable particle velocity is 20 in./sec for distances less than 50 ft. However, it was not found possible to damage the low-profile test concrete through elastic ground vibrations, and the writer concluded that it is generally necessary to have an additional nonelastic effect such as rupture of the supporting rock mass, some type of strong flexure of the concrete, or ground heave. For this reason, the TVA specifications include controls for such inelastic behavior of the supporting rock, and these are considered to be far more important than vibration limitations (Table 1 and Figure 5). For further discussion, see Oriard (*7*).

DATA PROCESSING

This discussion relates to the processing and analysis of ground vibration data from blasting. At first glance, it might appear that such data processing is a topic of little consequence to highway work. The reason for its presentation here is that the topic has proved to be a problem of some importance on a number of highway projects, and it is hoped that this discussion will mitigate the problem on future projects.

When ground vibrations are a matter of any interest on a highway project, it is common to monitor the blasting operations with a portable seismograph. Usually, one instrument is taken to different locations of interest as the work progresses, so many instruments are not used simultaneously. The data are usually plotted as a log-log graph of peak particle velocity versus scaled (normalized) distance, where scaled distance is the true distance scale (divided) by the square root (or cube root) of the charge weight per delay.

As the data are obtained and plotted, a trend begins to emerge, showing the manner in which the vibrations die out with distance from the blasting source. This is known as the "attenuation" of the vibration intensity with distance. A trend line through the data is used for predicting the intensity of future vibrations at various distances for various weights of explosives. If a large number of seismographs were placed at various distances from one blast, in similar geological settings for each instrument, the data would fairly represent the manner in which vibrations would be expected to die out in that area. On the other hand, if only one instrument is used to monitor consecutive blasts, there will usually be a fair amount of scatter in the data. Eventually a data band will emerge, with parallel upper and lower bounds, but the first few data points may suggest slopes that are physically impossible, even reverse slopes. In such instances, regression lines should be avoided.

The analyst is usually pressed to give predictions from the first blast onward. If he is not sufficiently experienced, he will be tempted to place too much reliance on a few scattered data points and calculations made from them. Hand calculators and computers can quickly calculate regression lines (and they are readily approximated by eye). There is an intuitive tendency to be more comfortable with actual data and calculations than with judgment that may or may not yet appear to be supported by the data. What often happens, then, is that a regression line is drawn through a number of points that is insufficient to fairly represent the true conditions. Because the line was calculated from actual data, an inexperienced person might extrapolate it, regardless of its slope or position on the graph. A more experienced person would know what slope to expect and would be aware of representative upper and lower bounds of such data.

On some projects, the premature plotting of regression lines has brought the project to a halt because of unfounded dire predictions of calamity. This came about because the regression line was very steep and indicated catastrophic results at the closer distances that would be found later in the work. The regression line was a false line plotted prematurely, but it brought about expensive delays in the work until the question could be resolved.

On one project in the Northwest involving partial removal of an existing concrete structure, the opposite conclusions were drawn about attenuation rates. The attenuation line was nearly horizontal, bringing the analyst to the conclusion that particle velocities would be very low even at the source. A serious conflict existed between the project owner and the contractor until this question was resolved. The problem was made worse by the analyst's lack of awareness that his seismic equipment was incapable of registering the true characteristics of the vibration. He was registering only a small fraction of the energy involved, and his equipment response became progressively less effective as the vibration frequencies increased close to the source. Because of this decreasing response, he concluded that very little energy was present.

The recommended solution to these problems is to begin with a reference data base so that new data can be placed in proper perspective. For those who might not have such data, it might be convenient to use some readily available published source of such data, such as the Oriard prediction curves (Figure 1), and other works *(1, 2, 8)*.

Figure 1 is a generalized plot of peak particle velocity versus scaled distance, where scaled distance is the true distance divided by the square root of the charge weight per delay. The data can also be represented by

$$V = 242\ (D/W^{1/2})^{-1.6}\ k_1, k_2, k_3, \ldots \qquad (1)$$

where

V = peak particle velocity;
D = true distance;
W = charge weight per delay; and
k-factors = variables such as confinement, spatial distribution, timing scatter, type of explosives, and the like.

When the combination of k-factors = 1.0, the equation represents the upper bound to typical down-hole blasting data. The line shown for high confinement or elasticity is represented by increasing the factor 242 to 605.

If the new data are plotted on such curves, it is easy to see whether the new data are high, low, or average. This assists the analyst in predicting future results. Also, unless the data show otherwise, an attenuation slope of the order of -1.6 should be used. Further, it is strongly recommended that the analyst plot upper and lower bounds rather than regression lines. Usually, it is far more important to know the upper bound than to know the average, despite the usual inclination to make use of statistical procedures and plot regression lines.

Of course, it is essential that the monitoring equipment be capable of responding accurately to the frequencies and the intensities of interest. Most vibrations for close-in small-scale blasting are far beyond the range of typical off-the-shelf blast-monitoring equipment.

CONCLUSION

Blasting is a technical art that must be tailored to the specific conditions of the site in question. The results that can be achieved are controlled strongly by site conditions. The more difficult the site conditions in relation to the desired result, the more time, money, and skill must be used to achieve the results. In some cases, these expenditures may be too great for the value received. In other cases, failure may be guaranteed in advance by specifications that require inappropriate procedures. Those persons involved in design, specifications, execution, and monitoring of the work need sufficient understanding of geology, rock mechanics, and blasting processes to define optimum procedures and results. Several common problems and methods of dealing with them have been discussed.

REFERENCES

1. L. L. Oriard. Blasting Effects and Their Control in Open Pit Mining. *Proc., Second International Conference on Stability in Open Pit Mining,* Society of Mining Engineers, New York, 1972, pp. 197–222.
2. L. L. Oriard. Blasting Effects and Their Control. In *Underground Mining Methods Handbook.* Society of Mining Engineers, New York, 1982, pp. 1590–1603.
3. R. A. Dick, L. R. Fletcher, and D. V. D'Andrea. *Explosives and Blasting Procedures Manual.* Information Circular 8925. U.S. Bureau of Mines, 1983.
4. L. L. Oriard. Modified Site Response Blasting: The Role of Rock Mechanics in Perimeter Control. *Proc., Tenth Conference on Explosives and Blasting Technique,* Society of Explosives Engineers, Montville, Ohio, 1984.
5. C. O. Faris. Dworshak Dam Underground Crushing Chamber. *Symposium on Underground Rock Chambers,* ASCE National Meeting, Phenix, Ariz., 1971, pp. 147–165.

6. A. J. Hendron, Jr. Engineering of Rock Blasting on Civil Projects. In *Structural and Geotechnical Mechanics* (W. J. Hall, ed.), Prentice-Hall, Englewood Cliffs, N.J., 1977.
7. L. L. Oriard and J. H. Coulson. TVA Blast Vibration Criteria for Mass Concrete. *Specialty Session on Minimizing Detrimental Construction Vibrations*, ASCE National Meeting, Portland, Oreg., 1980, pp. 101–123.
8. R. G. Tart, L. L. Oriard, and J. H. Plump. Blast Damage Criteria for a Massive Concrete Structure. *Specialty Session on Minimizing Detrimental Construction Vibrations*, ASCE National Meeting, Portland, Oreg., 1980, pp. 125–140.

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