# Avoiding Damage to Residences from Blasting Vibrations

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This paper presents some basic procedures for avoiding vibration damage to residences when blasting. Particle velocity of the ground near the residence is presented as the most suitable criterion for associating ground vibration with building damage. Two inches per second particle velocity is recommended as a safe vibration level.

A scaled distance, which is defined as distance from the blast to the point in question in feet divided by the square root of the maximum charge per delay in pounds, can be used as a guide for determining the amount of explosives allowable per delay. A scaled distance of 50 ft/lb$^{1/2}$ is offered as a safe limit if no seismic instrumentation is used to measure vibration levels from the blasts. A scaled distance less than 50 ft/lb$^{1/2}$ may be a safe limit when instrumentation has been used to establish vibration levels.

•THE PRIMARY purpose for the use of explosives in drill holes is to break rock. This problem has been studied carefully, and most blasters are well aware of the problems associated with rock breakage. Nevertheless there is a hazard associated with blasting that frequently is overlooked or ignored because it is not useful to the blaster. This hazard is the strong seismic waves generated by the blast that progress through the rock in all directions from the blast area. These seismic waves can adversely affect structures at considerable distances from the blast. Therefore, if damage is to be avoided when blasting, the users of explosives must know the basic fundamentals of the generation and propagation of seismic waves from blasting and the vibration levels of these waves that can be considered nondamaging.

Numerous criteria have been proposed to establish a maximum safe vibration level. Rockwell (5) in 1927 stated that, as a result of his instrumented tests, structures that are farther than 200-300 ft from a blast would not be damaged. He also pointed out the need for measuring vibrations from blasting in order to establish the level of vibration as a function of charge size and distance.

In 1942, Bureau of Mines Bulletin 442 reported particle acceleration as the best criterion for estimating damage to structures (6). For example, a particle acceleration of 0.1 g or less in the structure was labeled no damage, 0.1 to 1 g as caution, and a particle acceleration above 1 g was listed as possible damage.

F. J. Crandell (1) presented, in 1949, a criterion based for the first time on vibration levels in the ground in the vicinity of the structure. This criterion called for an energy ratio, which he defined as acceleration squared divided by the frequency squared. Where acceleration is in ft/sec$^2$ an energy ratio below 3 was considered safe and above 6 was called the danger area.

Numerous studies were performed and results, in which various criteria were suggested, were published between 1949 and 1960. During this time, particle displacement of 0.03 inches was adopted by several states as a safe blasting limit.

In 1957, Langefors, Kihlstrom, and Westerburg (4) proposed a criterion based on particle velocity in the ground near a structure. In this report, 2.9 ips was listed as producing no damage, but increasing velocities would then begin to produce damage.

Paper sponsored by Committee on Soil and Rock Properties and presented at the 45th Annual Meeting.

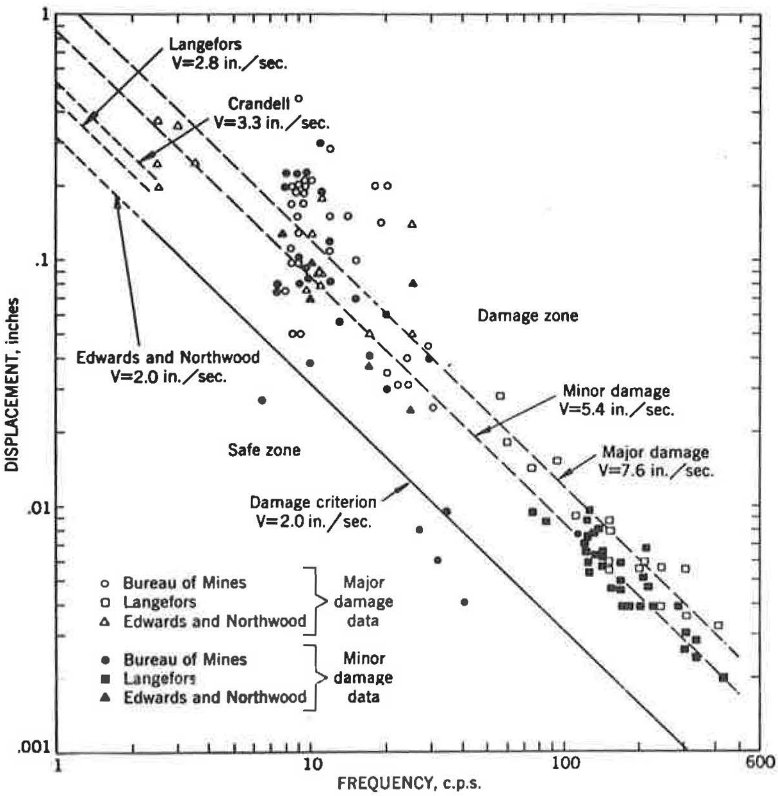


Figure 1. Recommended damage criteria.

Edwards and Northwood's paper (3) also set forth particle velocity as a criterion for damage control; 2 ips was considered safe by these researchers.

In 1959, the Bureau of Mines was requested to reinvestigate the problem of vibrations from blasting and their effect on structures. At that time it was noted that data concerning damage to structures are most difficult to acquire since intentional damage to structures for test purposes is costly, and unintentional damage becomes unavailable by legal proceedings and hostile witnesses. Therefore, one of the first tasks undertaken was a search of the literature and assembly of all published data on buildings that were damaged as a result of blasting vibrations. Of the numerous papers avilable only three reports included data along with the analysis and conclusions. These were the Bureau of Mines Bulletin 442 by Thoenen and Windes (6), the Hydro Electric Commission Report from Canada with Edwards and Northwood as the principal investigators (3), and the report by a group in Sweden under the direction of Langefors (4).

The three sets of data were combined and statistically analyzed to determine if one criterion could be considered more closely associated with building damage then any of the other criteria. When these combined displacement-frequency data were plotted on log-log coordinates, it became apparent that there were no significant differences among the data. Thus, even though these sets of data were obtained in different countries, by different researchers using varied instrumentation, the data could be pooled and treated as a single group. Figure 1 shows a composite plot of these data. From the statistical analysis of the data, it was concluded by Duvall and Fogelson (2) that damage to residences is proportional to particle velocity and that major damage (fall of plaster, serious cracking) can be expected at a particle velocity of 7.6 ips, minor damage (fine plaster cracks, opening of old cracks) at a particle velocity of 5.4 ips, and that 2 ips appears reasonable as a separation between a relative safe zone and a probable damage

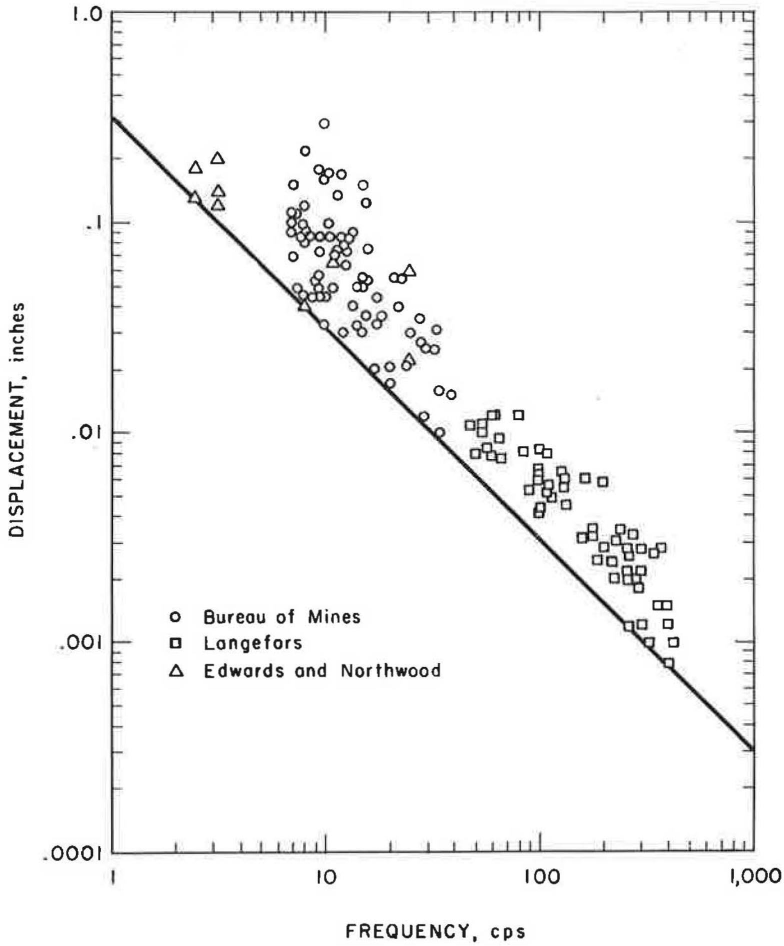


Figure 2. Displacement vs frequency for no damage.

zone. Incidentally, this safe limit agrees with that offered by Edwards and Northwood. This work was presented in a Bureau report and the criterion of 2-ips particle velocity has been generally accepted as a safe vibration level by people working in the field of blasting vibrations.

The fact that 2 ips is reached at a particular structure does not necessarily mean that damage will occur. Many structures and residences have experienced vibration levels greater than 2 ips without any observable damage. As an illustration, Figure 2 shows the 2-ips line through all the no-damage data points above 2 ips that could be found in the published literature.

From these investigations it has been concluded that if one or more of the three mutually perpendicular components (radial, vertical and transverse) of vibration in the ground near the structure have peak particle velocities in excess of 2 ips, there is a fair probability that damage to the structure may occur. Conversely, if the components of vibration in the ground near a structure have peak particle velocities less than 2 ips, there is a low probability that damage to the structure may occur. The probability of damage increases as the vibration level increases above 2 ips and the probability of damage decreases as the vibration level decreases below 2 ips.

With a safe vibration criterion established, the next problem was to determine what variables contributed significantly to the vibration level. Obviously, charge-size and

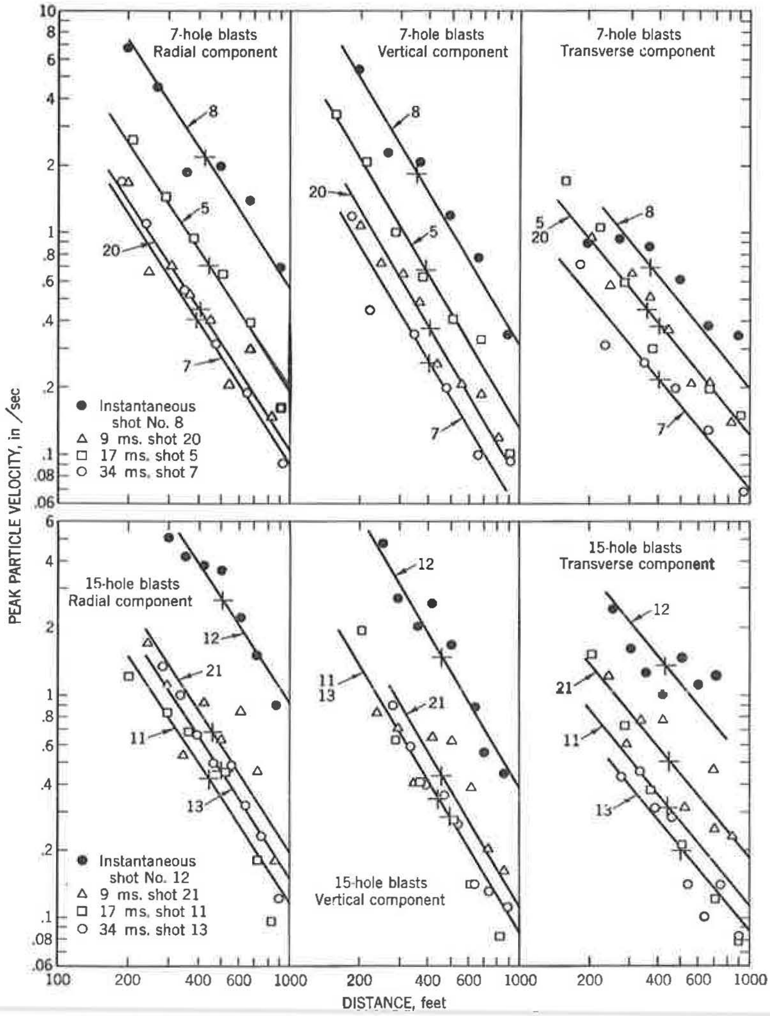


Figure 3. Particle velocity vs distance for 1- and 3-hole quarry blasts.

distance from the blast point to the structure in question are major factors controlling the vibration level. Thus, the development of a usable propagation law governing charge-size and distance became the next project.

The first tests consisted of a series of blasts ranging from 1 hole to 15 holes per blast. Delay intervals varied from zero to 34 milliseconds. The data from these tests plotted by component of velocity (radial, vertical, transverse) are shown in Figures 3 and 4. From a statistical analysis of these tests it was concluded that when a blast consists of several delays, it is the charge weight per delay and not the total charge weight that determines the vibration level. Secondly, the increase in the number of delays does not increase the vibration level. Finally, since straight lines fit the data well when the particle velocity data are plotted as a function of distance on log-log coordinates, an applicable propagation equation can be expressed in the form

$$V = HW^{\alpha} D^{-\beta} \tag{1}$$

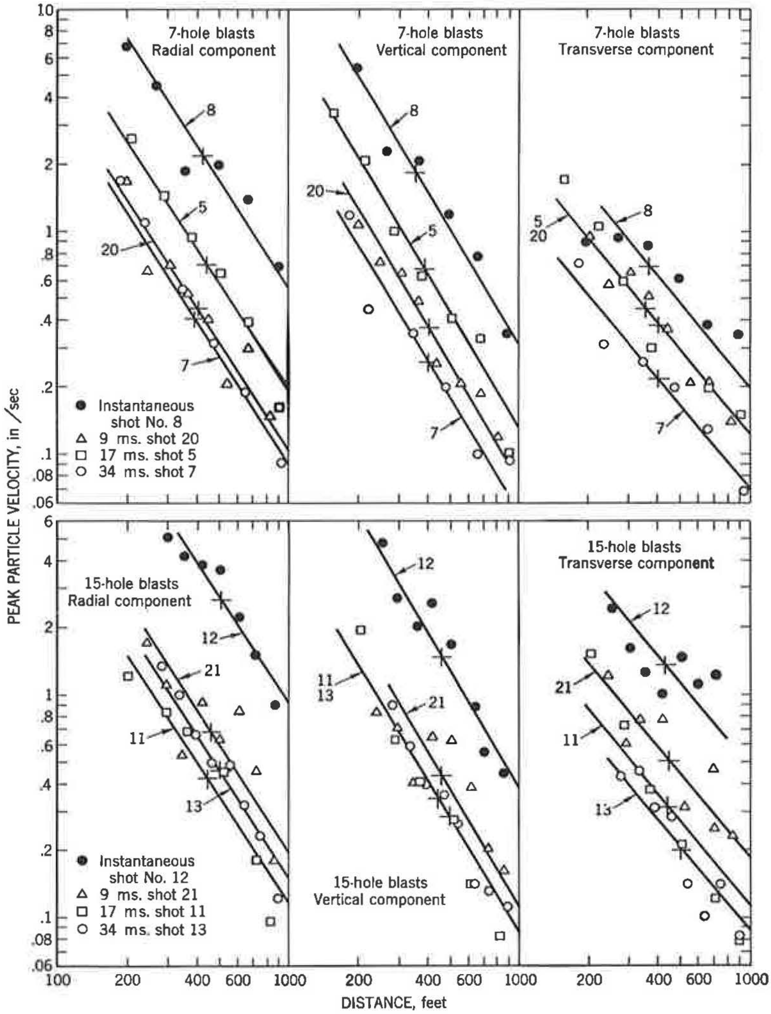


Figure 4. Particle velocity vs distance for 7- and 15-hole blasts.

where

$V$ = particle velocity, ips,
$W$ = maximum charge weight per delay, lb,
$D$ = distance from blast to measurement point, ft,
$H$ = constant for a particular site,
$\beta$ = exponent of D and the slope of the regression lines in Figures 3 and 4, and
$\alpha$ = exponent of W.

The exponents $\alpha$ and $\beta$ and constant H must be determined for each site considered.

From further testing at numerous sites it has been concluded that this general propagation equation can be expressed as

$$V = H\,(D/W^{1/2})^{-\beta} \tag{2}$$

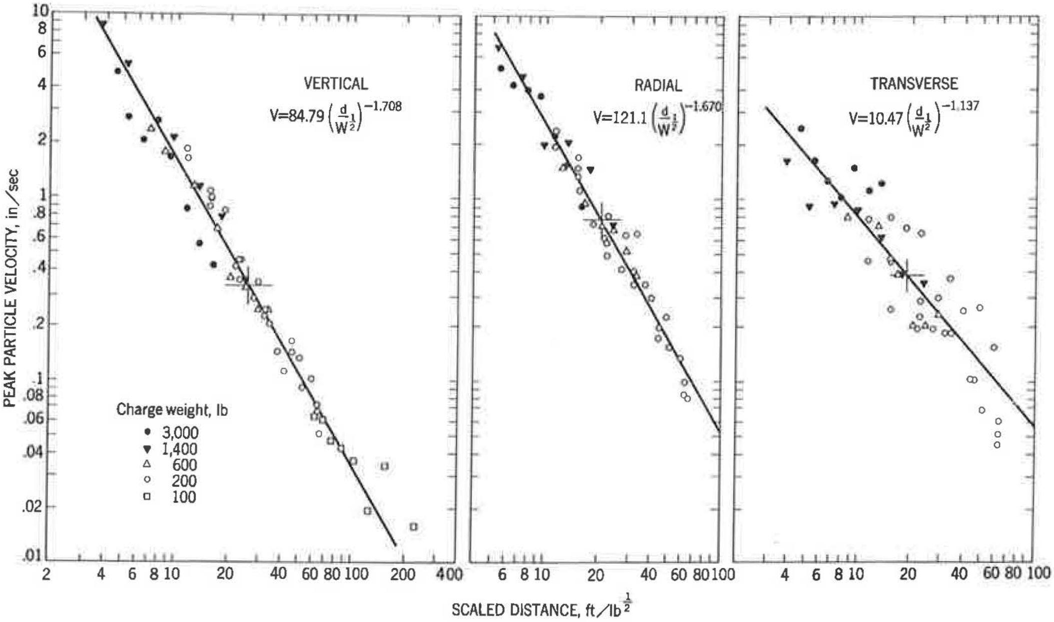


Figure 5. Particle velocity vs scaled distance for instantaneous blasts.

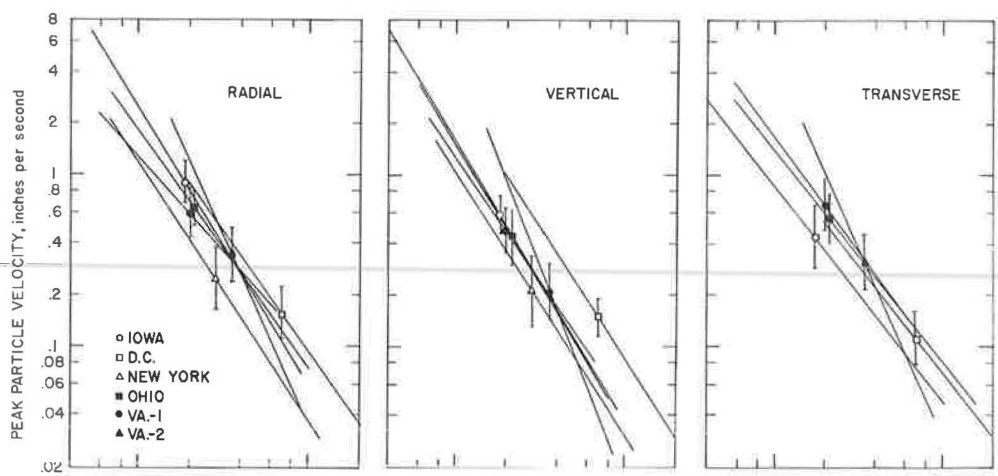


Figure 6. Particle velocity vs scaled distance, combined data.

where

D = distance from blast to measurement point, ft,
W = maximum charge weight per delay, lb, and
H = constant for a particular site.

When particle velocity data from one site are plotted on log-log coordinates as a function of the scaled distance $D/W^{1/2}$, good grouping of the data is

TABLE 1

MAXIMUM CHARGE WEIGHTS PER DELAY ALLOWABLE FOR SCALED DISTANCES OF 50 AND 20 FT/LB$^{1/2}$

| Distance (ft) | Maximum Charge Weight Per Delay | |
|---|---|---|
| | Scaled Distance (50 lb) | Scaled Distance (20 lb) |
| 100 | 4 | 25 |
| 500 | 100 | 625 |
| 1,000 | 400 | 2,500 |
| 2,000 | 1,600 | 10,000 |

obtained. An example of this grouping is shown in Figure 5. The plots in this figure show the same data as were presented in Figures 3 and 4. It can be seen from this figure that one could select a scaled distance for this particular site at which the safe vibration level would not be exceeded. This scaled distance could then serve as a guide for determining the amount of explosives that could be used without exceeding the safe vibration level.

Figure 6 shows the lines of least squares that have been placed through the particle velocity-scaled distance data from each of 6 quarries. To avoid confusion, each data point is not given, but the midpoint of the data is represented by a symbol. A minimum of 24 data points have been used to determine the slope and level of each of these lines. The length of each line represents the range of the data. The vertical line through each midpoint represents one standard deviation. The variation in the slopes and intercepts of the regression lines indicates that a large site effect is present. Therefore, if one wished to establish a scaled distance where the safe blasting vibration level of 2 ips would not be exceeded, the spread in these data must be considered.

For example, at a scaled distance of 20 ft/lb$^{1/2}$, a point that corresponds to 2 ips would be well outside of the spread in the data for the Iowa site, but would be within the spread in the data for the Va-2 site. Thus, a scaled distance of 20 ft/lb$^{1/2}$ could be used only if tests had been performed at the site in question and the results showed that the particle velocity-scaled distance curve is situated along the left side of the general plots shown in Figure 6. If, however, the data fall along the right side of these plots, a scaled distance of 20 ft/lb$^{1/2}$ could not be used. But a point which corresponds to the safe blasting vibration criterion at a scaled distance of 50 ft/lb$^{1/2}$ is well outside the spread in any of the curves shown and very probably any other quarry. Therefore, a scaled distance of 50 ft/lb$^{1/2}$ would provide a reasonable margin of safety for most quarry operations. But if one suspects that conditions are unique at a particular site, vibration measurements should be taken before establishing a minimum scaled distance as a safety limit. Table 1 gives some charge weights and distances that correspond to scaled distances of 20 ft/lb$^{1/2}$ and 50 ft/lb$^{1/2}$. If one has established that a scaled distance of 20 ft/lb$^{1/2}$ contains a reasonable safety factor, 25 lb of explosives per delay can be detonated and 2 ips will not be exceeded at a distance of 100 ft, the detonation of 625 lb per delay would produce vibrations below 2 ips at 500 ft, and so on. But if no measurements have been taken, a scaled distance of 50 ft/lb$^{1/2}$ should be used. Thus, 4 lb per delay is the maximum safe amount for a distance of 100 ft, 100 lb per delay for a distance of 500 ft, and so on.

There are other variables that can account for the spread in the data shown in Figure 6. At some quarries there is a variation in the propagation law parameters, H and $\beta$, with direction from the blast area. Therefore, if a scaled distance less than 50 ft/lb$^{1/2}$ is to be used, measurements should be made in each direction of possible vibration damage.

The type of rock in which the blasting occurs can have an effect on the level of vibrations that result from blasting. Therefore, if the scaled distance from the blast to a potential damage point is less than 50 ft/lb$^{1/2}$, new vibration measurements should be made when blasting operations are moved from one rock type to another.

The method in which the blast is detonated has a significant effect on the resulting vibration levels. For example, if a row of holes is to be detonated with detonating fuse and is initiated somewhere in the middle of the row of blast holes, a distinctly higher level will result than if the blast were initiated at one end. This is because two holes

detonate during each delay. Current investigations indicate that blasts detonated with electric caps produce vibration levels that can vary considerably. This variation is probably caused by the time spread in the initiation of a group of caps each with the same nominal delay. But, this spread can only result in a lower vibration level than anticipated.

There is a problem concerning instrumentation when one decides to use particle velocity as a safe vibration. Present seismographs are of the displacement type and instrumentation such as used by the Bureau of Mines, although accurate, is not generally satisfactory for routine measurement. There are no velocity seismographs commercially available at the present time, but several manufacturers have expressed interest in producing such an item. Also, components are presently available if one wishes to assemble a velocity measuring unit. However, peak particle velocity can be obtained from either displacement or acceleration records by differentiation or integration, providing accurate frequencies can be determined.

From the 6 years of quarry vibration investigation by the Bureau of Mines, it has been concluded that the vibration levels are not affected significantly by varying the type of explosives. This applies to the generally available commercial explosives used in the quarry industry.

## SUMMARY

Peak particle velocity is considered to be the best criterion for associating ground vibration with building damage, and 2-ips particle velocity is a safe vibration level to avoid vibration damage from blasting.

A scaled distance of 50 ft/lb$^{1/2}$ is considered safe even though instrumentation has not been used at the site in question. Scaled distance is defined as the distance from blast to point in question in feet divided by the square root of the maximum charge weight per delay in pounds.

Scaled distances less than 50 ft/lb$^{1/2}$ may be used as a safe limit if instrumentation has been used to establish the level at these points.

Method of initiation, direction from the blast, rock type, and rock attitude can have an effect on vibration levels.

## REFERENCES

1. Crandell, F. J. Ground Vibrations Due to Blasting and Its Effect Upon Structures. Jour. Boston Soc. Civ. Eng., pp. 222-245, April 1949.
2. Duvall, W. I., and Fogelson, D. E. Review of Criteria for Estimating Damage to Residences from Blasting Vibrations. Bur. of Mines Rept. of Inv. 5968, 1962. 19 pp.
3. Edwards, A. T., and Northwood, T. D. Experimental Studies of the Effects of Blasting on Structures. The Engineer, Vol. 210, Sept. 30, 1960.
4. Langefors, U., Kihlstrom, B., and Westerburg, H. Ground Vibrations in Blasting. Water Power, pp. 335-338, 390-395, 421-424, Feb. 1958.
5. Rockwell, E. H. Vibrations Caused by Quarry Blasting and Their Effect on Structures. Rock Products, Vol. 30, pp. 58-61, 1927.
6. Thoenen, J. R., and Windes, S. L. Seismic Effects of Quarry Blasting. Bur. of Mines Bull. 442, 1942. 83 pp.