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# Blasting and Building Damage

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## Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

When blasting operations are undertaken in a settled area, the occupants of the surrounding buildings often become aware of the accompanying ground vibrations. They notice for the first time certain cracks in their walls and foundations, and inevitably infer that the cracks were caused by the blasting. Usually they are mistaken, misled by the fact that the threshold of human perception of vibration is far below the threshold of structural damage; the cracks produced perhaps by settlement or shrinkage of materials have been there unnoticed for years. But damage can, and sometimes does, result from blasting. The circumstances in which it may will be discussed in this Digest.

### Mechanism of an Explosion

The objective of a blasting operation is to shatter material so that it may be removed. Beyond the region of material actually shattered and displaced, there is generally a relatively small region of plastic deformation and cracking, beyond this the remaining energy is propagated as an elastic wave in the ground. If the charge is near the surface there may also be propagation through the air. This will be referred to separately.

At short range a wave radiates spherically and the amplitude diminishes inversely as the distance from the blast. At longer ranges two other factors affect the propagation process: 1) the wave splits into three types of wave, which travel at different speeds; 2) variations in the medium, such as layering or fissuring, may introduce further scattering and dispersive effects; a major geological fault intersecting the path may largely prevent propagation in a particular direction.

All these factors tend to reduce the wave amplitude more than would be predicted on the basis of the inverse-distance law. The distance relations reported here are believed to be conservative, representing the vibration levels to be expected in relatively homogeneous elastic media at sufficiently close range that little dispersion has taken place.

### Properties of Blasting Waves

At the immediate site of an explosion the disturbance takes the form of a single pulse, whose peak amplitude and duration depend on the properties of the medium and the properties and size of the explosive charge. The resulting elastic wave usually has a strong initial build-up, followed by an irregular series of oscillations (Figure 1).

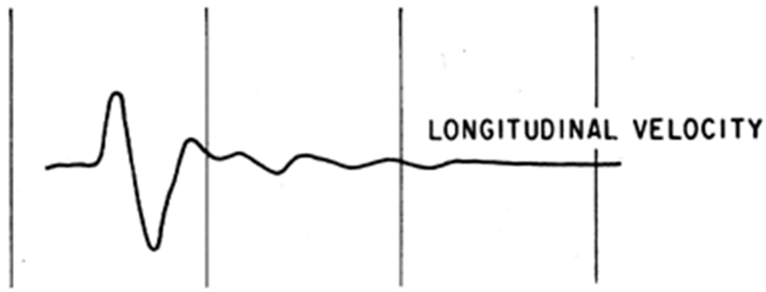


*Figure 1. Record of typical blasting vibration*

As the disturbance passes a given point an individual particle of the medium is displaced from its rest position. It is possible to record or measure this particle displacement; alternatively, one may record the particle velocity or acceleration. Though the three quantities are related, it is not a simple matter to deduce one from another because the wave is not a simple one. It is desirable therefore to measure the quantity that is most simply and generally related to damage.

There is no direct relation between absolute particle displacement and damage; it is relative displacement, or strain, that is important. Strain is another quantity that can, in principle, be measured, but in typical structures it varies unpredictably from point to point.

If the structure takes the form of a concentrated mass supported in a well-defined way, one can obviously determine the support forces by measuring the acceleration of the mass. Experimentally, particle acceleration in structures is found to provide a fairly good general index of probable damage.

If one considers an elastic wave progressing through an extended medium, the stress in the medium is directly proportional to the particle velocity. The relation depends on the elastic modulus of the material, but since there is a rough correlation between elastic modulus and elastic limit it may be expected that particle velocity will be a good general index of damage in the medium. This is borne out by the experimental observation that there is a very close correspondence between structural damage and the particle velocity in the portion of structure in closest contact with the soil. Figure 2 shows horizontal and vertical components of particle velocity in basement ways and their relation to the occurrence of damage. Velocity is recommended as the most consistent index of the probability of damage.

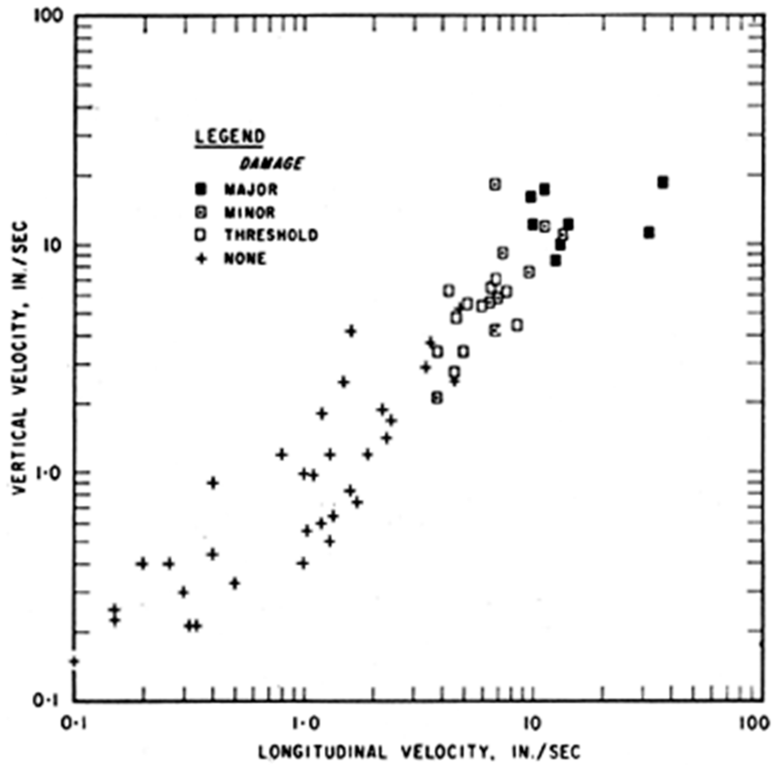


*Figure 2. Particle velocity and damage in basement walls*

**Nature of Damage from Blasting**

There is rarely a clear distinction between damage from blasting and damage from other causes. The following notes should, however, provide some guidance in post-mortem discussions or (preferably) in planning before-and-after examinations of structures. Prior inspections are strongly recommended whenever there is a chance that blasting vibrations will approach the damage threshold.

The first damage generally occurs in the basement wall nearest the explosion. The degree of involvement of the rest of the structure depends on the size of the charge and its distance from the structure. As the distance increases there is, of course, a corresponding increase in the charge required to produce damage, and as the charge increases the duration of the disturbance also increases. The result is that with larger charges the region of instantaneous disturbance increases, so that more and more of the structure tends to be in simultaneous vibration.

At ranges of 20 feet or less the area of damage is confined to a small portion of the basement wall nearest the charges. In a homogeneous way cracks will develop at the point closest to the charge and may be in any direction. If there are weaknesses in the walls in the vicinity of the nearest point, such as an opening or a construction joint or an old settlement crack, the new failure will of course prefer these areas. A unit masonry wall almost invariably fails along the joints between blocks.

At ranges of 20 to 100 feet the region of damage becomes less well-defined, though usually sell confined to the nearest basement wall. Construction joints, openings, old cracks and points of special constraint such as at the intersection with a flanking wall, all are likely locations for damage.

At ranges beyond about 100 feet the charges required to produce damage are sufficiently large that the resulting wave tends to act simultaneously over a substantial portion of the foundation. It is still probable that damage will occur first in the basement but there may also be evidence that the whole building was shaken horizontally from its foundations, somewhat as in an earthquake. Shearing may take place between foundation and superstructure or between lateral walls and longitudinal walls or floors. Masonry elements such as chimneys and parapets may develop displacements between the bottom courses and the upper section.

Damage from horizontal forces shows most clearly in buildings founded on rock or well-consolidated till. Buildings on softer soils, especially wet soils and those with prior evidence of settlement, most frequently suffer increased settlement

**Threshold of Damage**

From The relation between damage and particle velocity, as illustrated in Figure 2, it is concluded that the threshold of damage corresponds to a horizontal (or vertical) velocity of about 3 inches per second in the foundation walls nearest the blast. Note that this is for vibrations of the structure rather than the soil. There is some evidence that vibrations in the free surface of the soil itself may be higher than those in the structural walls, but the relation probably depends on the softness of the soil and the mass and rigidity of the structure. Similarly, it is possible to specify the threshold in terms of an acceleration (in the structure) of about g*, but the threshold value is not as well-defined as for velocity.

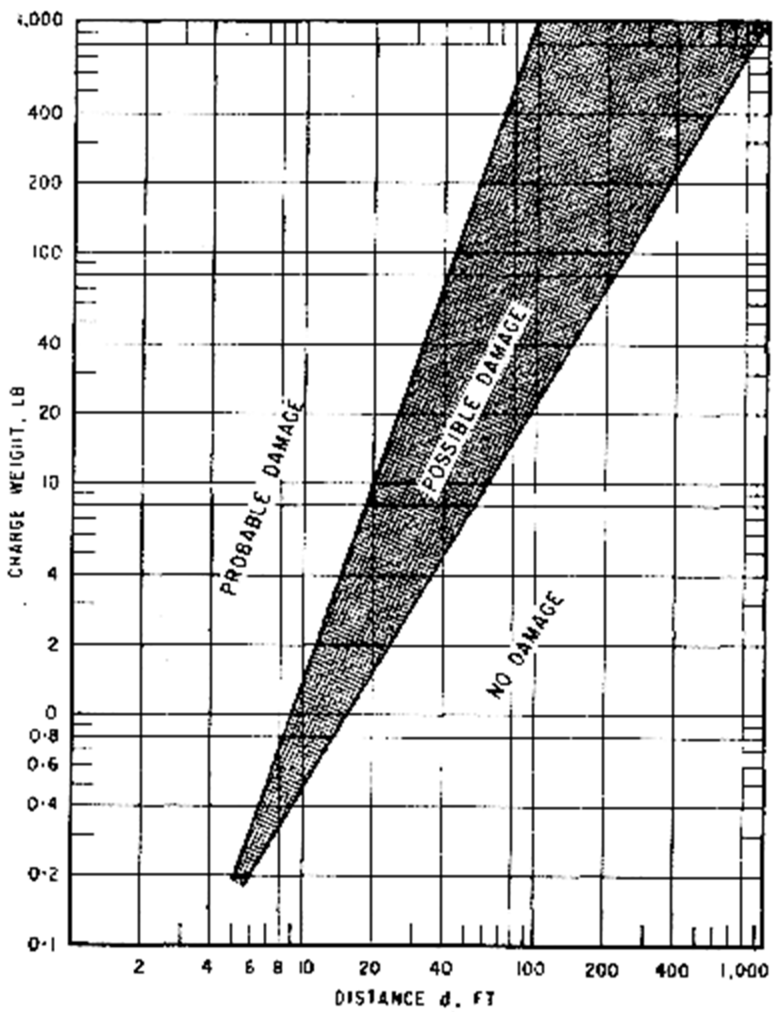


*Figure 3. Probability of damage versus charge and distance*

Obviously there must also be a direct relation between charge and distance and the probability of damage, though one can expect it to be affected by variations in the coupling of charge to medium, the nature of the intervening medium, and the coupling of medium to structure. The situation is summed up in Figure 3. The lower-right zone of the figure is the region in which damage is most unlikely; the upper left is the region in which it is very probable; the intermediate region is one in which, depending on the complexities mentioned above, damage may occur. A simple relation defining a conservative safe limit is $E^{2/3} = d/10$, where $E$ is the weight of a single charge in pounds and $d$ is the distance in feet.

Apart from the uncertainties mentioned, two others may be noted. There appears to be little variation pound for pound, among the common blasting materials in vibration levels produced at a distance. There is an interesting relation, however, between elastic vibration and rock breakage: if a charge does a good job of shattering and displacing the surrounding material, it produces slightly lower vibration levels than one that fails to break through to the free surface of the material. Within the building structure there is, of course, a correlation between damage and strength. Thus, a monolithic concrete wall in good condition will endure somewhat more than a unit masonry wall. These variables also affect the vibrations produced in the structure, and it is for this reason that particle velocity is a more precise index of the damage threshold than merely charge and distance. Consequently it is suggested that Figure 3 be used for guidance as long as charge and distance can be confined to the no-damage zone. Operations in the intermediate zone should be guided by vibration measurements.

**Multiple-Delay Blasting**

It is common practice in blasting to use not a single charge but a series of charges distributed through the batch of material to be removed. It is also useful to arrange that the charges are fired not simultaneously but at intervals of a few milli-seconds. This technique provides better results in terms of the blasting operation by improving the fragmentation of the material and leaving a better-defined rock face. It also results in greatly reduced vibration levels for a given total weight of explosive, because the individual delays spread the energy over a longer time. It is a fair approximation that the formulas for single charges apply if the total charge per delay is multiplied by 1.5.

**Notes on Monitoring Procedures**

Vibration monitoring procedures constitute a highly specialized subject beyond the scope of this Digest, but a few general remarks by way of background may be appropriate.

The measurement of vibration velocity is usually done by means of an electromagnetic pickup, whose resonance frequency is below the range of interest (say 2 or 3 cycles per second), connected to a suitable indicator. The indicator may take the form of a recording system or a simple meter. A recorder provides information about wave-form as well as amplitude, but is a bit elaborate for ordinary field use. A simpler alternative is one of the so-called impact noise meters, in which the meter retains for a few seconds the peak value of the signal reaching it. This provides only the maximum velocity, but for most monitoring purposes it is enough.

It has been emphasized that particle velocity is the most useful vibration parameter to measure, and that it is not easy to convert from, say, displacement to velocity. It is sometimes necessary, however, to make shift with available instruments that record displacement or acceleration. What can be done, with such instruments, to determine particle velocity in the structure?

The most common displacement-measuring instrument is the portable seismograph, which contains in one package three pendulum elements (for three components of vibration) together with optical and recording apparatus. The unit thus comprises a bulky, heavy object very critical as to level, that cannot readily be fastened to a structural wall. At best it can be used to determine movement of the ground surface. Because of its weight, however, it must generally be placed on a rigid surface such as pavement or on a special panel that has somehow been brought into good contact with the soil. Because the accelerations that give rise to damage are close to g, it is necessary to fasten it down to the mounting surface.

Assuming that a faithful record of ground displacement is obtained, the next problem is to infer the particle velocity. This cannot be done on the assumption that the vibration is sinusoidal because generally it is not. The most useful method of interpretation is to locate the regions of maximum slope on the record and use these slopes to determine the velocities. This amounts to a graphical differentiation of the interesting parts of the record.

Another common type of instrument is a portable accelerograph, similar to a seismograph except that the moving elements are resonant at a frequency above the region of interest. Perhaps the best procedure is not to attempt to deduce velocity (which would require a graphical integration process), but simply to use the acceleration criterion indicated earlier.

**Minor Causes of Blasting Damage**

Sidewalk superintendents at a well-designed blasting operation are usually disappointed: there is a slight thump of ground vibration, a little dust over the site, and that is all. More spectacular effects such as air blast and flying rock are usually evidences of unskillful or careless techniques undesirable even from the viewpoint of efficient blasting; they mean that powder is being wasted.

Flying rock may result from inadequate stemming or back-filling, or poor design of charges (too much powder in too few holes). Unpredictable break-throughs sometimes occur, however, in cracked or inhomogeneous material, and it is prudent, if there are buildings, people or equipment nearby to use a safety mat. Most municipal regulations require it in any case.

Air blast results when the explosive is inadequately covered. Generally there is no difficulty with the explosive proper if the drill holes are back-filled. Sometimes, however, the charges in an array are connected by lengths of a detonating material, which itself may produce substantial air blast if the surface sections are left exposed. The problem can be solved by covering the detonating material with a few inches of sand or other convenient fill. Even snow provides-good protection.

Apart from a major catastrophe, damage from air blast is usually confined to window breakage. Windows in walls facing the blast are the most susceptible, although special focussing and reflection effects may involve other areas if there are a number of buildings in the vicinity. Studies made by the U.S. Bureau of Mines have shown that overpressures of the order of 100 pounds per square foot are required to break ordinary windows. It should be noted that window breakage may result indirectly from ground vibration if a flexible frame building is heavily shaken by a blast; in this case the broken windows will probably be in the walls longitudinal to the direction of the blast.

**Acknowledgements**

These notes are based on a review of the literature, but more particularly on the results of research studies made jointly by the Research Division of the Hydro Electric Power Commission of Ontario and the National Research Council (Reference 1).

1. Northwood, T. D., R. Crawford and A. T. Edwards. Blasting vibrations and building damage. The Engineer, Vol. 215, No. 5601, 31 May 1963, p. 973-978.

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* g = acceleration due to gravity