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# **Rock Blasting Fundamentals**

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# Chapter 88

## CONTROLLED AND MONITORED ROCK EXCAVATIONS IN URBAN AREAS

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Lack of understanding of useful applications of explosives on construction work stem primarily from the fact that explosion is commonly associated with destruction. On rock excavation and other construction works a certain quantity of explosive is harnessed to perform useful work at the source e.g. blasts to disintegrate rock. Development in rock blasting techniques, including the use of multiple-row blasting with short delay ignition, have made it possible to excavate rocks close to or below buildings even in closely built-up areas. To permit the use of explosives on construction projects, in ways that will not damage existing structures, guidelines have been developed from careful measurements of intensity of ground vibrations. Accurate electronic instruments are now available for doing this.

### PLANNING AND CONTROL

Blasting operations must be carefully planned and carried out to avoid discomfort to persons or damage to property. This increase in the use of rock blasting in city areas alone has led to a number of problems due to ground vibrations, air shock waves, and the psychological effect of noise. While the latter seldom if ever causes damage, it does create irritation and discomfort to persons living or working near the blasting sites. A result of this is a steady increase in the number of complaints in respect of damage to houses and other premises. Many such complaints are genuine and damage may undoubtedly be caused when incorrect blasting techniques are used.

Inevitably most, if not all, blasting operations are used as a basis for complaints, even when the techniques employed can cause neither damage nor discomfort. The solution of these problems is two fold. Firstly to determine acceptable threshold values for varying degrees of damage, and secondly to have a reliable instrument for measuring ground vibrations that can cause damage.

Existing Criteria: Many damage criteria have been proposed. Some of the best knowns are those of Langefors in Sweden, Edwards in Canada and Morris in United States with a re-evaluation of the original U. S. Bureau of Mines data. The general consensus of these men is that the "peak particle velocity" of the ground is the best criterion for evaluating vibration in terms of its potential to cause damage (Wiss, 1968). It has also been found that the vibration potential of a blast will be determined by a ratio of the distance and the square root of the explosives weight (pounds per delay); this ratio is called the Scaled Distance (S.D.).

Project Details: The authors were involved in controlling and monitoring rock excavations that were made by blasting faces up to 40-feet deep. This was for the construction of several multi-story buildings for the urban renewal project on the perimeter of the main downtown water front section of Halifax, Canada. The project covered many small city blocks, several of which contained old multi-story structures. Figure 1 shows the existing bedrock contours, final excavation levels and the locations of blast monitoring stations. The site is underlain by slate formation including narrow bands of quartzite and weathered shaley slate.

It is the blaster, the man responsible for loading and firing the blast, who determines the size, spacing, and depth of drill holes. The licensing of blasters may certify to their skill in the use and handling of explosives, but it conveys very little about their planning capabilities. Such planning may have to be furnished by others in order to provide the needed equipment, and, as is so often the case in excavation, such planning must be bolstered by information. It is usually the "cut and try" method - the "drill and blast" method that finally must be utilized to during the initial planning phase of the excavation.

The opportunity to perform blast monitoring services, to assist the contractor in controlling his blasting operations, provided an interesting exercise in the planning and execution of this type of

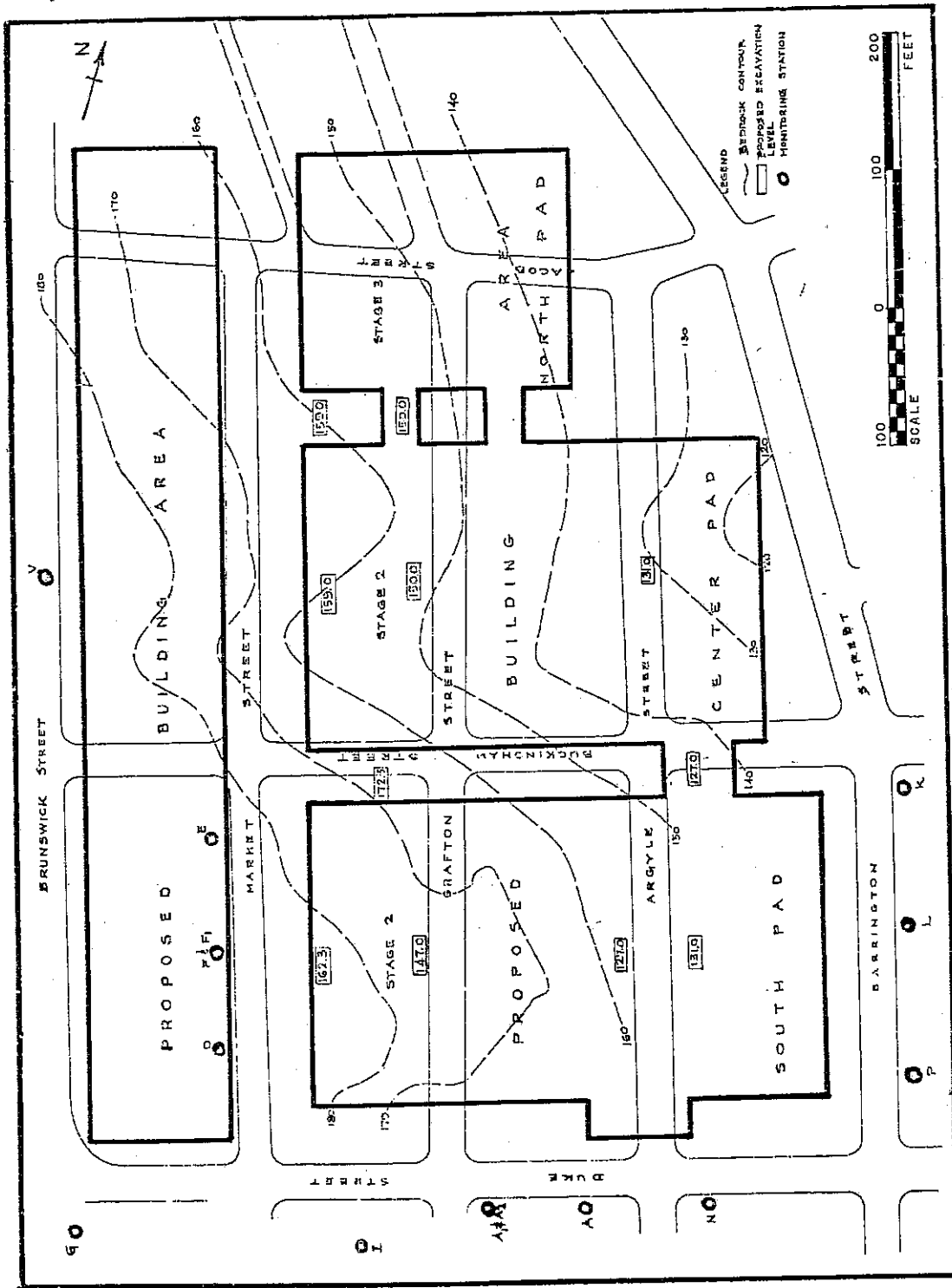


Figure 1 - Plan of the Project Site

project (2). As a planning aid vibration monitoring is effectively applied by determining the safe limits of explosives that can be used. During actual operations it is the definite tool for measuring vibrations and is invaluable as a legal safeguard against damage claims.

Instrument: A three component portable seismograph (Sprengnether model VS-1100) was used to monitor the blasts and is shown in Figure 2. This portable seismograph has separate detector and recording modules.

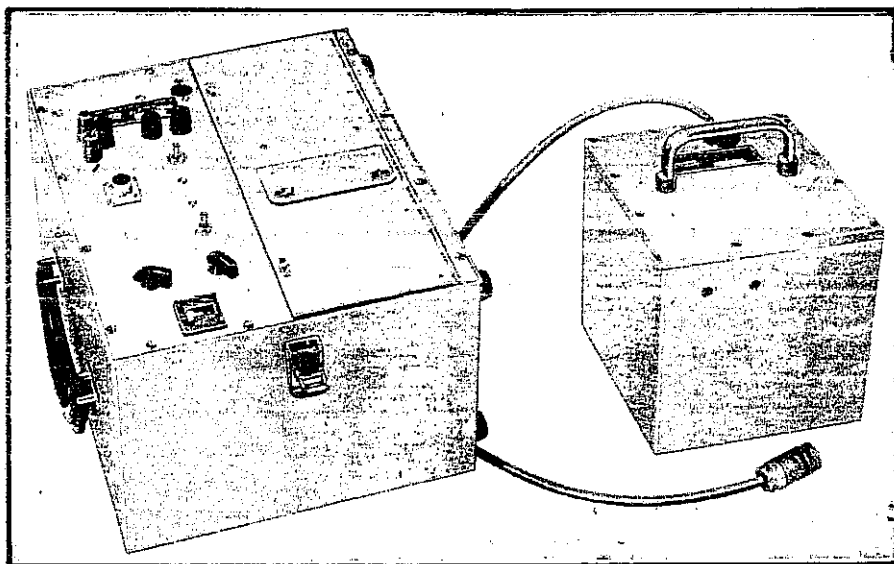


Figure 2 - Sprengnether Seismograph (Model VS-1100)

The detector module has three orthogonal electromagnetic seismometers contained in a 7-inch cube. This cube weighs 19.5 pounds and has a soil-density of 1.6 gm./cc. It may be buried at a place which is remote from the recording module. Each transducer is the stationary magnet-suspended coil type. The recording module contains a four channel, constant speed camera using high frequency (200 Hz) galvanometers. The camera accepts light-tight supply and take-up magazines holding up to 200 feet of 2.75 inch direct-write or standard photographic paper. The recording module is self-contained operating from an internal, rechargeable battery.

This portable seismograph can produce from 0.20 to 20 inches of record motion per inch/second of ground motion having a flat response on the velocity trace from 1.8 to 250 cycles per second. A typical vibration recording of longitudinal, vertical and transverse (L-Z-T) wave component caused by blasting is illustrated on Figure 3. Timing lines are at 0.02 second intervals and every tenth line is accentuated.

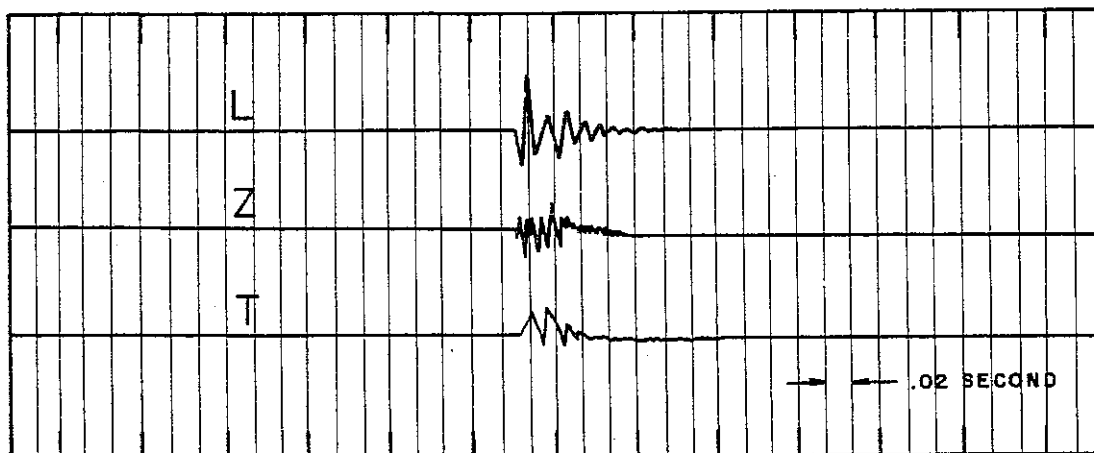


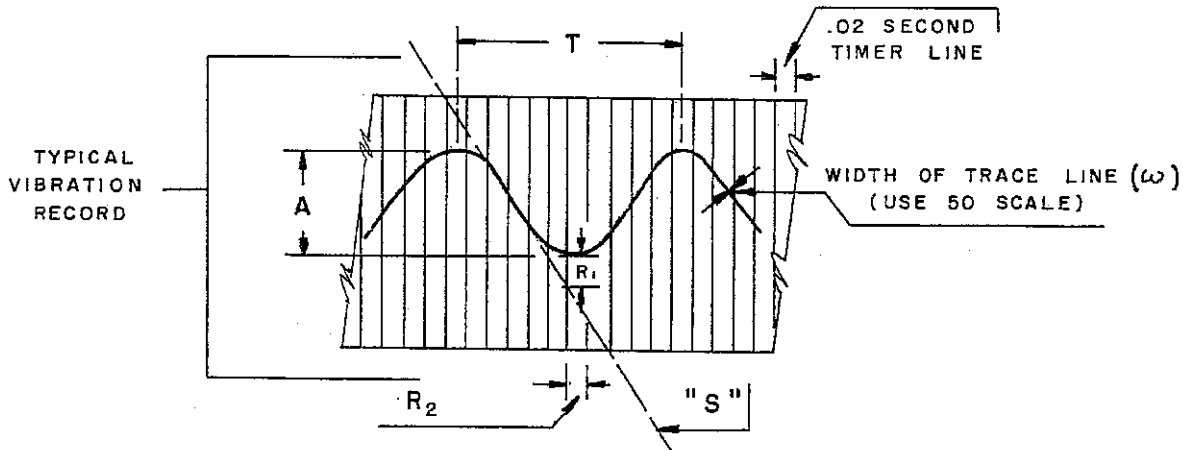
FIGURE 3 VIBRATION RECORD OF VS-1100 BLAST SEISMOGRAM

The analysis is thus reduced to the determination of ground velocity from the vibration record. Other derived quantities include acceleration ( $a$ ), displacement ( $A$ ), and frequency ( $f$ ). The method used to analyze a vibration record to compute the true maximum ground particle velocity and other derived quantities is illustrated in Figure 4.

For most engineering purposes it is usually the maximum value of the vibration that is sought, and thus the largest excursion of the seismogram trace are measured. For our analyses the Bureau of Mines damage criterion concerned with the maximum amplitude on any of the three traces was used.

#### FIELD DATA AND INTERPRETATION

Figure 5 shows the results of the blast monitoring services on the project, the data applies only to this site. The points plotted represent measured vibration intensity (peak particle velocity,  $v$ ) from the blasting. The initial charge loading schedule (1) was developed with a factor of safety of 2 as applied to ground velocity



### VELOCITY DETERMINATION (v)

VELOCITY = SLOPE OF DISPLACEMENT TRACE "S"

VELOCITY =  $R_1 \times .01$  ( $R_1$  IS NUMBER OF INCREMENTS  
MEASURED ON 50 SCALE)

eg: IN ABOVE RECORD VELOCITY =  $7.5 \times .01 = .075$  IN./SEC.

### FREQUENCY DETERMINATION (f)

T = PERIOD ; f = FREQUENCY

FREQUENCY =  $\frac{1}{T} = \frac{1}{(T) \times .02}$

eg: IN ABOVE RECORD - FREQUENCY =  $\frac{1}{11.5 \times .02} = \frac{1}{.23} =$   
4.3 CYCLES/SECOND

### DISPLACEMENT DETERMINATION (A)

DISPLACEMENT OR AMPLITUDE =  $A - 2\omega$

A = NUMBER OF INCREMENTS (MEASURED ON 50 SCALE)

$\omega$  = WIDTH OF TRACE LINE (MEASURED ON 50 SCALE)

eg: IN ABOVE RECORD DISPLACE =  $.28 - .02 = .26$  INCHES

ASSUME INSTRUMENT HAS A "100 GAIN".

DISPLACE =  $\frac{.26}{100} = .0026$  INCHES

### ACCELERATION DETERMINATION (a)

ACCELERATION =  $(1) f^2 \times \text{AMPLITUDE} = f^2 \times A$

eg: IN ABOVE RECORD: ACCELERATION =  $1 \times (4.3)^2 \times .0026 =$   
.00048 % GRAVITY

FIGURE 4: VIBRATION RECORD ANALYSIS

of 2 inches/second which is equivalent to an Energy Ratio (E.R.) of 1. The allowable charge size was based on a Scaled Distance (S.D.) of 20. Data from early stages of blasting was found to be well within allowable limits.

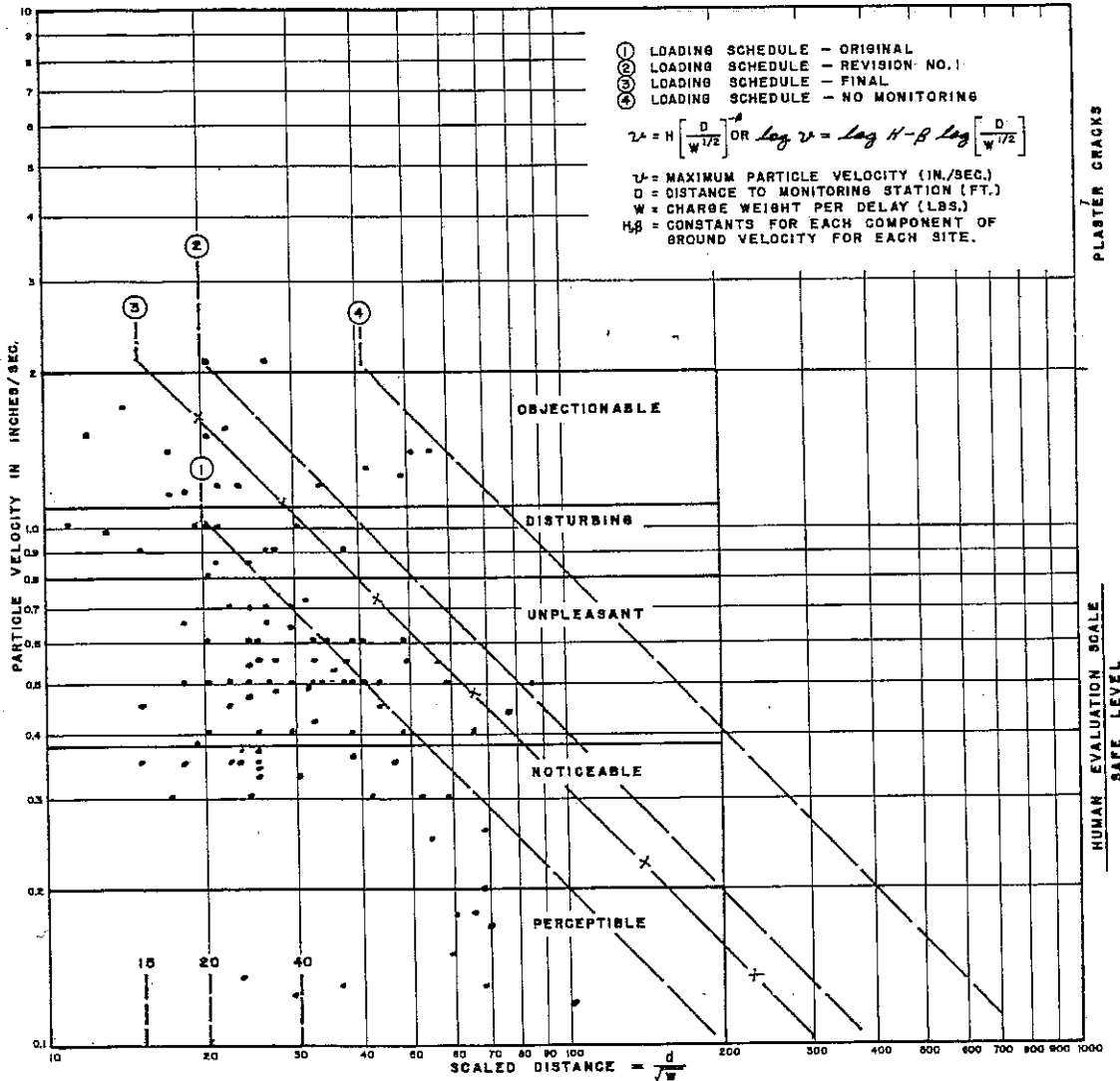


Figure 5 Peak particle velocity (a measure of vibration intensity) plotted against scaled distance, with a human evaluation scale added.

Accelerations converted to percent of gravity were found to be approximately equal, in numerical magnitude, to the velocity as illustrated in Figure 6. A correlation coefficient close to 1 was obtained. Due to the small displacement, the accelerations were not critical thus particle velocity was confirmed as the controlling factor. As the blasting progressed and more data became available the allowable loading schedule was revised ② (revision no. 2)



and the final recommendations were made based on schedule ③ . It incorporated the safe blasting criterion of 2 inches/second occurring at scaled distances of 15 to 20 ft. /lbs.  $1/2$ . For foundation blasts at the site which, were not seismographically monitored, a scaled distance of 40 was recommended.

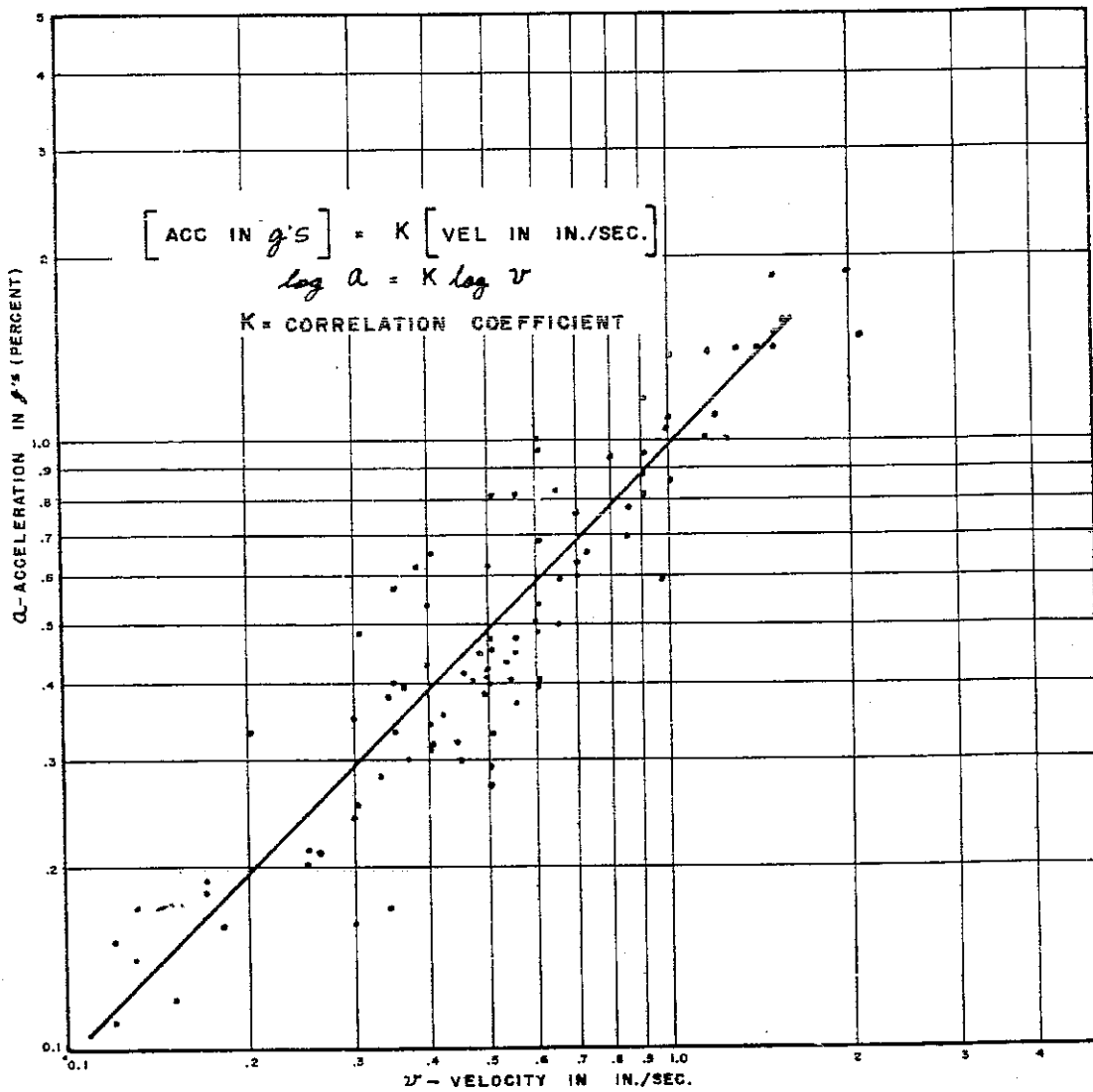


Figure 6 Correlation curve showing peak particle velocity ( $v$ ) against acceleration converted to percent of gravity ( $a$ )

Evaluation of the data developed a propagation equation of the form:

$$v = H \left[ \frac{D}{W^{1/2}} \right]^{-\beta}$$

or. 
$$v = \log H - \beta \log \left[ \frac{D}{W^{1/2}} \right]$$

a straight line on a log-log plot with intercepts of  $\log H$  and negative slope of  $\beta$  as illustrated in Figure 5.

where,  $v$  = Maximum Particle Velocity (in. /sec.)  
 $D$  = Distance, Source to Detector (ft.)  
 $W$  = Charge Weight per Delay (lbs.)  
 $H, \beta$  = Site Constants for each Component of Ground Velocity for each Excavation Site.

Controlling criteria for this site included a maximum peak particle velocity of 2.0 inches per second, a maximum displacement of 0.03 inches, and an energy ratio of not more than 1. A review of the measured data indicated that peak particle velocity of 1.0 inch per second was recorded about 15% of the time and velocities greater than 1.5 inches per second occurred about 3% of the time. There were only two shots where the above criteria were exceeded. One shot showed a peak velocity of 2.0 inches per second with Energy Ratio of 1.2 obtained for the other. Displacements computed at ground surface caused by the subsurface shots are summarized in Table I. Peak particle velocity of 2.1 inches per second corresponded with a displacement of 0.04 inches.

Human Sensitivity to Vibrations: In addition to structural response to ground vibrations from blasting it is necessary to consider human response. The obvious objectives of a successful rock blasting operation are reduction in damage complaints and an avoidance of erosion in public relations. Under ordinary conditions it is the house vibrations that an individual feels and not the ground vibrations directly. This partially explains damage complaints when the ground vibrations are at a markedly sub-damage level. Then too, blast vibrations are a transient phenomenon, and the steady-state conditions of most of the human vibration measurements do not have a sufficient time to develop.

TABLE I. DISPLACEMENT AT GROUND SURFACE CAUSED BY SUBSURFACE SHOTS

WEIGHT OF EXPLOSIVE "W" LBS.	DISPLACEMENT (IN FRACTION OF INCH) AT VARIOUS DISTANCES									
	<100'	110' TO 150'	150' TO 200'	200' TO 250'	250' TO 300'	300' TO 350'	350' TO 400'			
<100	.011, .001 AT 70', .0019, .0003	.0096, .0041, .0017 .00025, .00025 .0005, .0024	.0008	.0017	.002	—	—			
100<W<200	.001	.0037 .00134	—	—	.0014	—	—			
200<W<300	—	.0003, .0008 .0021	.00127, .0016 .026	.0014	.001	—	—			
300<W<400	—	.001, .006 .0006, .0013	.0018, .0019, .0016 .00127	.0022, .00095 .0024, .00077	.002	—	—			
400<W<500	—	.0017, .0025, .0027 .0018, .002	.0016, .0013, .0012 .0018, .0008, .04 .0024, .0017	.004	.0008 .0017	—	—			
500<W<600	.0034 .0011	.00135, .00056 .0006, .0035, .0029, .0024, .0063	.00128 .0048	.0015, .0010 .0009, .003	.0016 .0013	—	.0008 AT 440'			
600<W<700	.0008	.002, .0016 .0005, .0019	.002 .0026	.0014 .0014	—	.0015 .002	—			
700<W<800	—	.0032	.001 .0023	.0008	.014	—	—			
800<W<900	—	—	.0008	.00064 .0022	.00115	—	—			
900<W<1000	—	—	—	—	—	—	.001 AT 420' .00047 AT 530'			
1000<W<1100	—	—	.0096	.0022 .00147	—	—	—			
1100<W<1200	—	.0023	—	.00134 FOR 1233 LBS.	—	—	—			

Fig. 1. 10'

Wiss (3) recently published the results of human response to blasting vibrations in the form of peak particle velocity versus scaled distance versus human response. Figure 5 shows the monitored data as compared with the human evaluation scale. The blasts were noted to be disturbing and objectionable about 10 percent of the time and were unpleasant 50 percent of the time. We feel that the few cases of apparent minor damage such as falling tiles, dust, etc., which were reported were probably more the result of a substandard condition of maintenance of the building rather than the result of excessive ground movement due to the blasting activity. We believe that humans are disturbed long before structural damage can reasonably be expected to occur.

### CONCLUSIONS

The following findings are intended to provide useful information for safe rock blasting operations in urban areas and add to or improve upon existing knowledge in this field.

1. Planning of rock excavation projects in built-up areas should incorporate factors such as pre and post-blast survey of surrounding structures, relative economy involved for an accelerated excavation at the expense of neighbor's complaints and specific site characteristics.
2. Site parameters should be established from initial experimental blasting, based on a factor of safety of 2 with respect to a particle velocity of two inches per second and a scaled distance of 20.
3. To preclude damage to the surrounding structures values of 2.0 to 2.5 in. -per-sec. particle velocity and 20 to 15 scaled distance are recommended as safe blasting limits, however, lower limits are suggested to minimize complaints.
4. Scaled distance of 40 should be used as a guide to blasting if no monitoring instrument is used.
5. Millisecond delay blasting tends to reduce vibration levels as compared to instantaneous blasting.

## ACKNOWLEDGEMENTS

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