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Monitoring Rock Blasting for Tunnel Construction

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SYNOPSIS A program for the monitoring of rock blasting operations for the construction of a sewer tunnel has been discussed. A summary of observations together with pertinent conclusions and recommendations regarding the blasting operations, the potential for damage to nearby structures and criteria for safe blasting operations has been presented. It is recommended that peak particle velocity be restricted to two inches per second in horizontal direction at the nearest existing structure to prevent cracking of walls.

INTRODUCTION

A sewer tunnel with an internal diameter of 8 feet 6 inches is presently under construction as part of the wastewater system improvements and pollution control program for the City of Flint, Michigan. The engineering firms of Hubbell, Roth & Clark, Inc. and Neyer, Tiseo & Hindo, Ltd. are working as lead engineering and geotechnical engineering consultants, respectively, for the construction of the project. A portion of the tunnel will pass through sandstone bedrock. In an effort to fracture the sandstone bedrock in advance of the tunnelling operations, blasting activities from the ground surface have been conducted. The data discussed in this article is part of a monitoring program for the blasting activities along a portion of the alignment of the tunnel.

GENERAL SUBSURFACE CONDITIONS

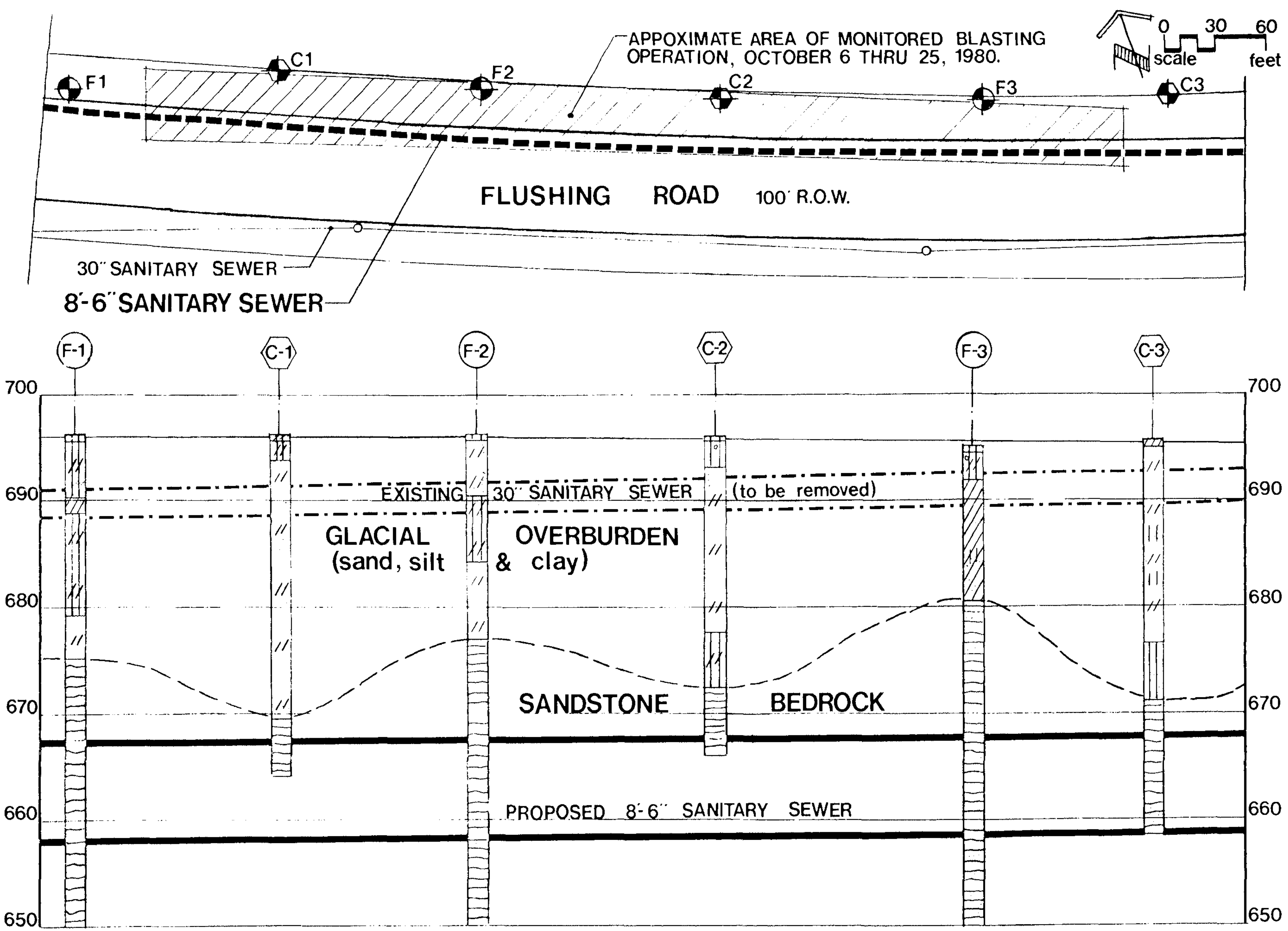
The general subsurface condition along the alignment of the tunnel within the area of the interest is shown in Figure 1. The invert of the tunnel will be at a depth of approximately 40 feet below the ground surface. The depth of the overburden soils ranges from approximately 15 to 30 feet. The composition of the overburden soils, which are glacial outwash, ranges from compact and very compact sand materials to very stiff and hard silty clay soils. The bedrock is a late Paleozoic gray sandstone with occasional partings and seams of shale and siltstone. The quality of the sandstone is somewhat variable, with the RQD of core-samples determined at the time of the test borings being noted to range from less than 10 for the upper weathered zone to more than 90 for the underlying competent sandstone. The static groundwater table was noted to be at a depth of approximately 5 feet below the ground surface.

BLASTING PROGRAM

The charges per hole consisted of loads of either 100 pounds of dynamite or 150 pounds of gellinite. The explosive charges were installed in 8 to 10-inch diameter holes drilled with a Drilltech Drilling Rig. Occasionally, casing was required to maintain the hole before the explosives were placed. The charges were spaced vertically to coincide with the tunnel face shown in Figure 1, and were detonated with Dupont Primer Cord and blasting caps. The resultant blasts generally consisted of one to six explosions controlled by millisecond delays. In several instances, relief holes were drilled in addition to the charged holes.

MONITORING PROGRAM

The vibrations induced by the blasting operations were monitored in the field with Model MD-81 vertical velocity transducers manufactured by the Electronic Systems Division of Geosource, Inc. (see Figure 2). In general, an array of three geophones was utilized to monitor each blast. Typically, two of the geophones were epoxy mounted on the concrete of the curb of an existing road parallel to the tunnel alignment. These transducers were located at least 200 feet apart at stations ahead of the blast location. The third geophone was generally located in the vicinity of the tunnel certerline and was coupled to the soil by means of a spike attached to the base of the transducer. A typical spacing and configuration of the geophone array for a blast is shown in Figure 3. Although it was considered desirable to also use horizontal velocity transducers, they could not be utilized due to the limited number of channels available in the recording equipment used during this study.



SCALE: HORIZONTAL: 0 30 60
VERTICAL: 0 2 5 10

FIGURE 1 - GENERAL SUBSURFACE CONDITION ALONG TUNNEL ALIGNMENT WITHIN AREA OF BLASTING.

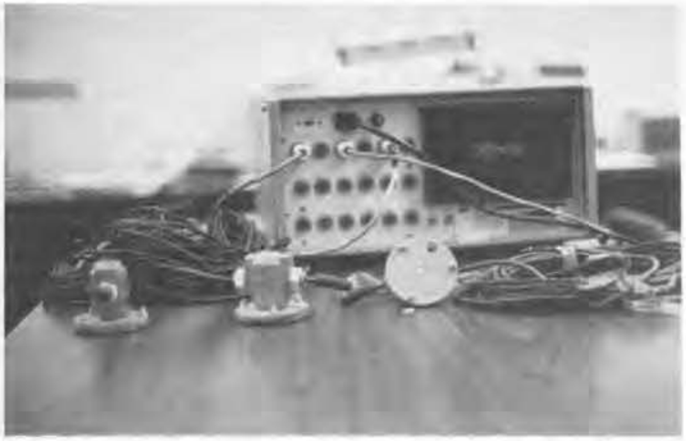


Figure 2 MD-81 Vertical Velocity Transducer

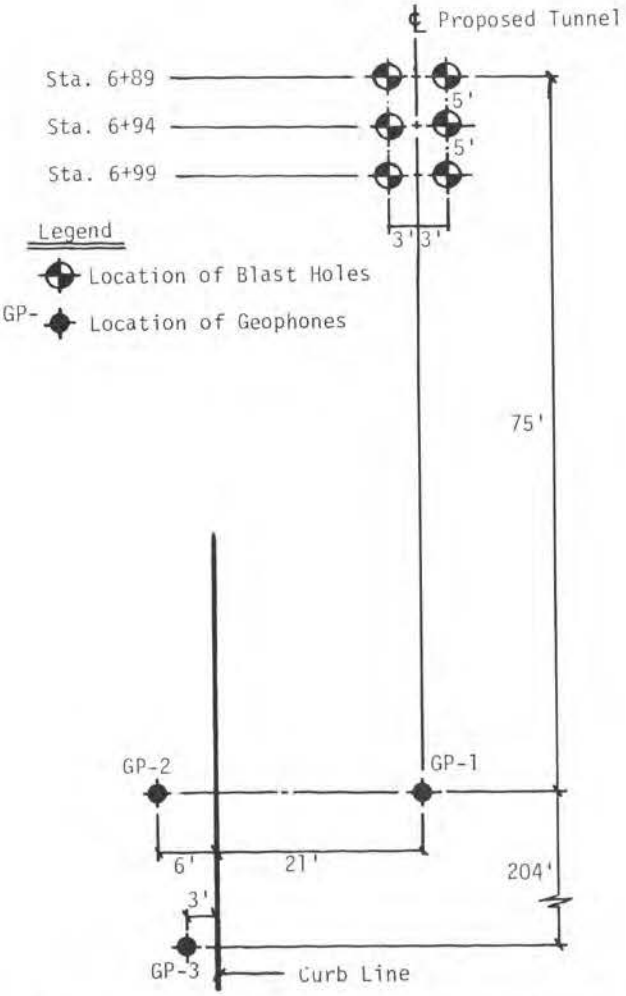


Figure 3 A Typical Spacing and Configuration of the Geophones for Monitoring of a Blast

The output from the geophones was input into a Honeywell Model 1858 oscillographic recorder (Figure 4). This recorder was equipped with Model 1881-HGD high gain differential amplifier modules. This equipment produced a permanent graphical record of the actual voltage output of each of the geophone stations on light sensitive paper. Due to the large voltage outputs experienced, the minimum output sensitivity range of 500 millivolts per division was generally utilized for the channel whose geophones were located nearest the blast. For the more distant geophone locations, a sensitivity setting of 200 millivolts per division was typically utilized. To get sufficient resolution of the high frequency pulses, the paper speed of the recorder was typically set at either 40 or 80 inches per second.

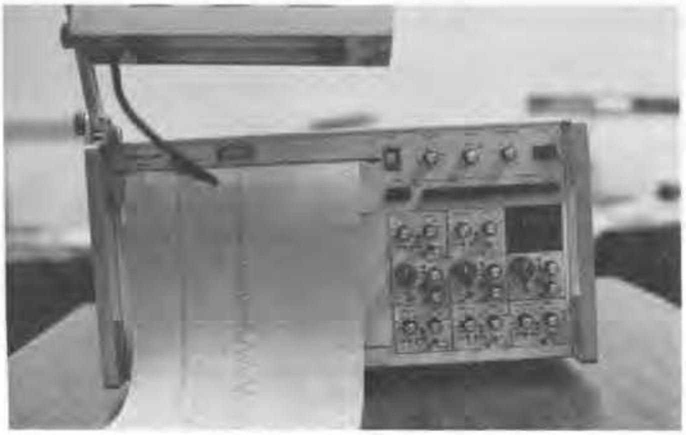


Figure 4 Oscillographic Recorder with High Gain Differential Amplifier Modules

The voltage output records developed for each geophone were evaluated to determine peak particle velocity and frequency of the blast induced vibrations. The graphical plot shown on the oscillographic records is actually a representation of output voltage (i.e. velocity induced in the transducer by the blast vibration) versus time. By dividing the output recorded voltage shown by a geophone constant of 0.87 volts/inch/second, the particle velocity at that instant can be evaluated. The following example calculation is presented for clarity:

Output from record = 4 volts
Geophone constant = 0.87 volts/inch/second
= 0.87 volts/velocity

Particle velocity = 4 volts ÷ 0.87 volts/inch/second
= 4.60 inch/second

By examination of the geophone records, the maximum voltage output for each geophone was determined and the peak (maximum) particle velocity for that record computed.

OBSERVATIONS, ANALYSES AND EVALUATIONS

The frequency of one complete wave cycle was evaluated for that portion of the velocity wave which produced the peak particle velocity. The seismic (compression) wave velocity (s) was also determined for each blast by the difference in arrival times at two geophone locations:

$$s = \frac{\text{Distance Between Geophones}}{\text{Difference in Arrival Times}} = \frac{D}{\Delta t}$$

The soil strains induced by the blast vibrations were also computed during this study in accordance with the following equation presented by the Corps of Engineers (1972) and Dowding & Corsen (1980).

$\epsilon = \frac{v}{s}$ Where ϵ = Soil strain in inches/inch

v = Particle velocity in inches/second

s = Seismic wave velocity in inches/second

Maximum soil strains at the geophone locations were thus developed on the basis of the compressive wave velocity and peak particle velocities evaluated from the geophone output records. It should be noted that had ϵ been calculated on the basis of shear wave velocity, it would be almost twice as large as that determined for the compression wave case.

The measured and computed properties are presented in Tables I through IV. Tables I, II and III present data for each geophone pertaining to the time of blast, charge size and number of delays, geophone location, measured maximum geophone output in volts, computed peak particle velocity and frequency of the single wave containing the peak particle velocity. Also presented on Tables I, II and III are the number of delays observed on the velocity record and the number of the shot corresponding to the computed peak particle velocity. Table IV presents data pertaining to the computation of seismic velocity (s) and maximum compressive wave soil strain (ϵ) developed from the geophone records.

Evaluation of the data presented in Tables I, II and III generally indicates that the highest peak particle velocities occurred nearest the blast site. At the location of Geophone No.1 (in the soil over the approximate centerline of the tunnel) and Geophone No. 2 (on the concrete pavement nearest the blast) the peak particle velocities were noted to range from approximately 4.1 inches/second to as much as 20 inches/second. At the location of Geophone No. 3 (on the pavement at the greatest distance from the charges), the peak particle velocities were noted to be substantially lower than those measured closer to the blast. At this location, the peak particle velocities were generally observed to range from approximately 1.7 to 9.5 inches/second. Frequencies of the peak particle motions were generally in the range of 40 to 60 cycles per second at all three geophone locations.

Review of the data presented on Table IV indicates that the compression wave velocity for this portion of the tunnel alignment is generally in the range of 8330 to 9250 feet per second. These values correspond reasonably well with the data developed during our previous seismic profiling of this portion of the alignment. Evaluation of the observed peak particle velocity together with the seismic velocity indicates soil strain values at Geophone Locations 1 and 2 ranging from approximately 0.6×10^{-4} to 2.0×10^{-4} inches/inch. As would be expected from the corresponding lower peak particle velocity values, the soil strain values at the location of Geophone 3 ranged from approximately 0.16×10^{-4} to 0.86×10^{-4} inches/ inch.

Review of the data developed herein indicates that the highest particle velocities occurred when the number of explosions, as indicted by oscillographic records, were less than the number of planned detonations. As shown on Tables I, II and III, the data also indicate that, where this occurred, the peak particle velocities were approximately twice the magnitude of the peak particle velocities measured when the number of planned and observed detonations was the same. Based on the foregoing, it appears that adjacent charges may have detonated simultaneously and that the higher velocities are the result of the combined energy released.

Review of the damage criteria recommended by the U.S. Bureau of Mines and the Corps of Engineers generally indicates that, for residential structures, the maximum safe peak particle velocity is on the order of 2.0 inches/second when excitation frequencies are greater than 50 cycles/second. Based on these criteria, it also appears that some minor damage may occur at velocities between 2.0 and 5.4 inches/second, with more extensive damage anticipated as the peak particle velocities increase.

Review of the data presented herein generally indicates that the peak particle velocities observed at Geophone Locations 1 and 2 during this study are well in excess of the 2.0 inches/second safe vibration range. Furthermore, these velocities are generally in the range where major damage to residential structures would be possible. At Geophone No. 3, the observed peak particle velocities are generally in the safe range, with measured velocities primarily ranging from 1.7 to 2.8 inches per second. However, these velocities (at high frequency) will probably cause severe dish rattle within homes and startle the occupants.

Inasmuch as the peak particle velocity is a function of the magnitude of the explosive loading and the distance from the shot for a given site, a plot of the observed peak particle velocity versus scaled distance has been developed and is presented herein as Figure 5. Since the blast holes are relatively closely spaced and charges generally exploded individually, the scaled distance was developed by

TABLE I - Observed and Computed Data for Geophone No. 1

Approximate Geophone Station	Distance From Closest Hole (Feet)	Explosive Charge (Pounds)	Planned Number of Delays	Number of Delays Observed	Delay Number of Maximum Geophone Output	Maximum Geophone Output (Volts)	Peak Particle Velocity (Inches per Second)	Frequency (Peak Particle Wave) in Cycles Per Second
7+87	100.0	1&2 @ 100# 3 @ 150#	3	2	2	11.9	13.6	45.7
7+87	100.0	-	-	-	-	3.53	4.1	-
8+10	111.0	1&2 @ 150# 3 @ 120#	3	3	1	17.5	20.1	42.6
8+41	132.0	1&2 @ 150# 3&4 @ 120#	4	3	3	10.8	12.4	53.3
8+99	133.4	1 @ 100# 2&3 @ 120#	3	2	1	5.0	5.8	46.5
9+02	130.0	1 @ 90# 2 @ 150#	2	2	2	4.0	4.5	49.1
9+20	120.0	1,2&3 @ 150#	3	3	1	5.7	6.5	51.3
9+20	110.0	1,2,3&4 @ 150#	4	3	1	7.5	8.6	45.7
9+20	100.0	1,2,3&4 @ 150#	4	4	1	9.25	10.6	42.1
9+51	96.5	1 thru 6 @ 150#	6	6	1	11.6	13.3	42.8
10+66	196.0	1 thru 6 @ 150#	6	3	2	6.8	8.7	61.5
10+66	181.0	1 thru 6 @ 150#	6	3	3	7.8	10.0	53.3

TABLE II - Observed and Computed Data for Geophone No. 2

Approximate Geophone Station	Distance From Closest Hole (Feet)	Explosive Charge (Pounds)	Planned Number of Delays	Number of Delays Observed	Delay Number of Maximum Geophone Output	Maximum Geophone Output (Volts)	Peak Particle Velocity (Inches per Second)	Frequency (Peak Particle Wave) in Cycles Per Second
7+87	100.0	1&2 @ 100# 3 @ 150#	3	2	2	15.6	17.9	50.0
7+87	100.0	-	-	-	-	7.45	8.6	50.0
8+10	111.0	1&2 @ 150# 3 @ 120#	3	3	1	10.4	11.9	49.1
8+41	132.0	1&2 @ 150# 3&4 @ 120#	4	3	3	6.3	7.2	42.6
8+84	118.0	1 @ 100# 2&3 @ 120#	3	2	1	7.8	9.0	50.6
8+84	112.0	1 @ 90# 2 @ 150#	2	2	2	6.7	7.7	43.7
9+20	120.0	1,2&3 @ 150#	3	3	1	6.5	7.5	56.3
9+20	110.0	1,2,3&4 @ 150#	4	3	1	9.9	11.4	50.0
9+20	100.0	1,2,3&4 @ 150#	4	4	1	10.9	12.6	49.1
9+61	106.5	1 thru 6 @ 150#	6	6	1	14.8	17.0	44.9
10+22	152.0	1 thru 6 @ 150#	6	3	2	5.6	6.5	50.0
10+22	137.0	1 thru 6 @ 150#	6	3	3	8.0	9.2	46.2

TABLE III - Observed and Computed Data for Geophone No. 3

Approximate Geophone Station	Distance From Closest Hole (Feet)	Explosive Charge (Pounds)	Planned Number of Delays	Number of Delays Observed	Delay Number of Maximum Geophone Output	Maximum Geophone Output (Volts)	Peak Particle Velocity (Inches per Second)	Frequency (Peak Particle Wave) in Cycles Per Second
9+77	290	1&2 @ 100# 3 @ 150#	3	2	2	1.5	1.72	53.3
9+83	284	1&2 @ 150# 3 @ 120#	3	3	1	2.4	2.8	48.8
10+66	357.3	1&2 @ 150# 3&4 @ 120#	4	3	3	1.44	1.7	40.0
11+00	334.4	1 @ 100# 2&3 @ 120#	3	2	1	1.73	2.0	61.5
11+00	328.4	1 @ 90# 2 @ 150#	2	2	2	1.72	2.0	44.4
11+20	320	1,2&3 @ 150#	3	3	1	1.79	2.06	53.3
11+20	310	1,2,3&4 @ 150#	4	3	1	2.3	2.64	84.2
11+20	300	1,2,3&4 @ 150#	4	4	1	2.4	2.8	84.2
11+46	291.5	1 thru 6 @ 150#	6	6	1	8.3	9.5	56.7
12+44	374.0	1 thru 6 @ 150#	6	3	2	1.5	1.7	56.3
12+44	359.0	1 thru 6 @ 150#	6	3	3	2.0	2.3	50.0

TABLE IV - Computed Data for Seismic Velocity and Maximum Compressive Wave Soil Strain

			(Geophone No. 1)		(Geophone No. 2)		(Geophone No. 3)	
Distance Between Geophone 2&3 (Feet)	Difference in Arrivals Time (Second)	Compression Wave Velocity s Feet/Second	Peak Particle Velocity v Inches/Second	Maximum Soil Strain $\epsilon = v/s$ Inches/Inch	Peak Particle Velocity v Inches/Second	Maximum Soil Strain $\epsilon = v/s$ Inches/Inch	Peak Particle Velocity v Inches/Second	Maximum Soil Strain $\epsilon = v/s$ Inches/Inch
190	.0215	8840	13.6	1.28×10^{-4}	17.9	1.69×10^{-4}	1.72	0.16×10^{-4}
190	.0210	9047	4.1	0.38×10^{-4}	8.6	0.79×10^{-4}	-	-
173	.0205	8439	20.1	1.98×10^{-4}	11.9	1.17×10^{-4}	2.8	0.28×10^{-4}
225	.0270	8333	12.4	1.21×10^{-4}	7.2	0.72×10^{-4}	1.66	0.16×10^{-4}
216.5	.0238	9097	5.8	0.53×10^{-4}	9.0	0.82×10^{-4}	2.0	0.18×10^{-4}
216.5	.0245	8837	4.5	0.42×10^{-4}	7.7	0.73×10^{-4}	2.0	0.19×10^{-4}
200	.0235	8511	6.5	0.64×10^{-4}	7.5	0.73×10^{-4}	2.06	0.20×10^{-4}
200	.0210	9524	8.6	0.75×10^{-4}	11.4	1.00×10^{-4}	2.64	0.23×10^{-4}
200	.0230	8696	10.6	1.01×10^{-4}	12.6	1.21×10^{-4}	2.8	0.27×10^{-4}
185	.0200	9250	13.3	1.20×10^{-4}	17.0	1.53×10^{-4}	9.5	0.86×10^{-4}
222	.0250	8880	7.8	0.73×10^{-4}	6.5	0.61×10^{-4}	1.7	0.16×10^{-4}
222	.0250	8880	10.0	0.94×10^{-4}	9.2	0.86×10^{-4}	2.3	0.12×10^{-4}

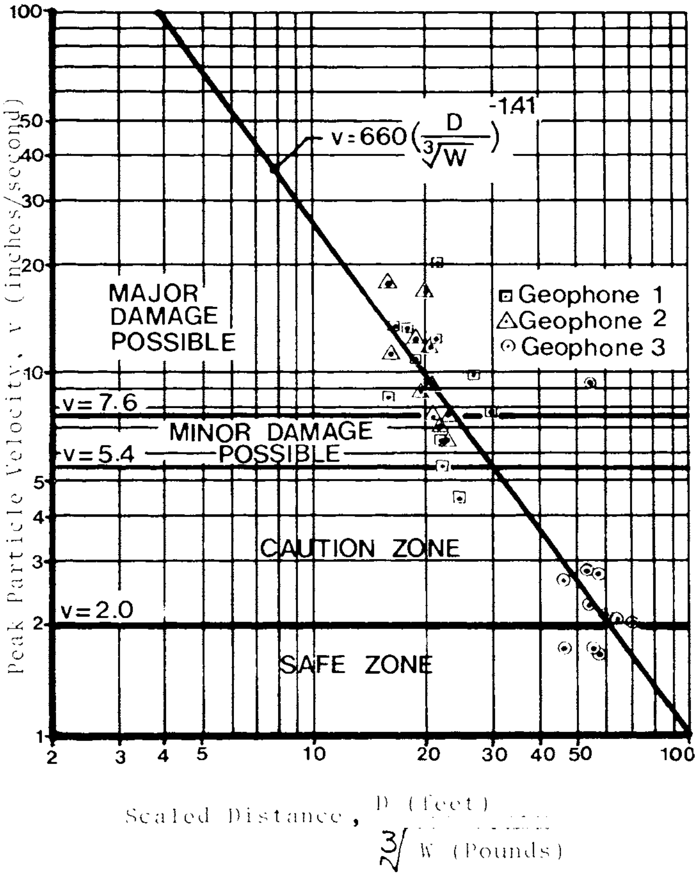


Figure 5 Plot of Peak Particle Velocity Versus Scaled Distance

modeling the blasting as a single point source exitement. Using this model, the scaled distance equation becomes:

$$\text{Scaled Distance} = \frac{D}{\sqrt[3]{W}}$$

Where D = distance from shot feet

and $\sqrt[3]{W}$ = cube root of the weight of explosive charge per delay— weight measured in pounds.

The damage criteria for residential structures has also been superimposed on Figure 5. Based on an evaluation of the data presented on Figure 5, it would appear that damage to residential structures would be unlikely for a scaled distance (combination of distance and weight of charge) where the resultant peak particle velocity was less than 2 inches/second.

For charge weights of 100 pounds, the distance beyond which a velocity of 2.0 inches/second or less would be expected is approximately 280 feet. For 150 pound charges, the corresponding distance is approximately 320 feet. Corresponding larger distances would be computed where adjacent charges explode simultaneously.

CONCLUSIONS

Based on the data developed during this phase of the blasting activities, it appears that the present system of charges, spacings and delays generate vertical peak particle velocities which vary in magnitude depending primarily on size of explosive loading and distance from the shot. At distances of less than approximately 280 feet, the measured peak particle velocities were generally in excess of the 2.0 inches/second maximum particle velocity criterion outlined by the Corps of Engineers for a safe blast vibration limit. Thus, it appears that if the present blast procedures are continued, there is substantial potential for damage to nearby residential structures.

In view of the above discussion, it was recommended that the contractor be restricted to the production of a particle velocity less than 2 inches/second at the nearest structure to prevent cosmetic cracking of the walls. Evaluation of the data presented on the scaled distance plot indicates that this can probably be achieved by modifying the charge size.

It was also recommended that the blasting activities be monitored on a full-time basis wherever these blasts occur within 500 feet of a privately owned residence. Since the soil and rock profiles affect the particle velocities and soil strains, and some variations in rock and soil profiles are possible, a continuous monitoring of the blasting operations was considered necessary.

It should be noted that only vertical velocities were measured during this study. It is proposed to monitor particle velocity on three orthogonal axes during the next phase of the work. By measuring the velocities on the vertical and both horizontal axes, it is anticipated that the maximum particle velocity and directional affects may be evaluated for this site. These new data can then be evaluated with respect to damage potential.

The monitoring program is still in progress and more data will be available at a later date.

ACKNOWLEDGEMENTS

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REFERENCES

Corps of Engineers (March, 1972)
Systematic Drilling and Blasting for Surface Excavations, Engineering Manual EM 1110-2-3800.

Dowding, C.H. and P.G. Corsen
"Cracking and Construction Blasting: Importance of Frequency and Free Response", ASCE Journal pre-print.

Kuesel, T.R. (June 1969)
"Earthquake Design Criteria for Subways", Journal of the Structural Division.

Langefors V. and B. Kihlstrom (1978)
The Modern Technique of Rock Blasting, John Wiley & Sons.

Wiss, J.F. and H.R. Nicholls (1974)
"A Study of Damage to a Residential Structure from Blast Vibrations", American Society of Civil Engineers, Special Report.