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THE GROUND VIBRATION ASSOCIATED WITH PIPE BURSTING IN ROCK CONDITIONS

Dr. Alan Atalah, P.E.[1]

[1] College of Technology, Construction Dept., Bowling Green State University, Bowling Green, OH

ABSTRACT

Researchers investigated the ground vibration associated with pipe bursting in soft soils and developed guidelines for the safe distance from existing nearby utilities, structures, and pavement. These studies aided the pipe bursting industry to grow and safely burst many miles of pipe near existing utilities and structures. However, the ground vibrations associated with bursting large diameter pipe imbedded in a rock trench are not thoroughly investigated. Theoretically, in tight rock trenches, the bursting head applies considerable amount of energy to create a pathway for the expander. The ground vibrations resulting from that energy may be considerable and may cause significant damage to nearby utilities, structures, and pavement.

The hard limestone rock around Bowling Green State University (BGSU) provided ideal setting to study the ground vibrations due to bursting large diameter pipes imbedded in rock trenches. The construction industry supported BGSU in investigating and developing guidelines for the safe distance for building and utilities from the pipe bursting operations. The research aimed to refine the safe limits for the bursting process in terms of trench width, bedding material, degree of up-sizing, and proximity to existing services. This paper discusses the experiment design, analysis of the collected data, and recommendations.

Keywords: pipe bursting, rock, ground movement, Ground vibration, pneumatic and static pull bursting systems.

INTRODUCTION

Rock formations provide a significant challenge for open cut excavation especially if the rock is hard and the line is deep (sewer lines). Open cut excavation in rock is slow, costly, risky, and disruptive. The needed energy to dig the rock results in high vibrations and ground movement that disrupt the structural integrity of nearby asphalt, utilities, and structures. The rock layers usually underlay a layer or more of soft soil where most of the shallow utilities (water, gas, cables, etc.) are placed with asphalt pavement on the top. In these situations, rock trenchers cannot operate and conventional rock excavation produces ground vibration that causes significant damage. If the construction team can safely burst and upsize an existing pipeline, a large cost saving is achievable (Atalah 2001). The pipe bursting process involves ground vibration in the proximity of the pipe. The magnitude of the vibration correlates with the distance from the bursting head, the amount of upsizing, the diameter of the pipe, and the type of soil. Owners of both the burst pipe and near by structures have legitimate concerns when bursting a large diameter line

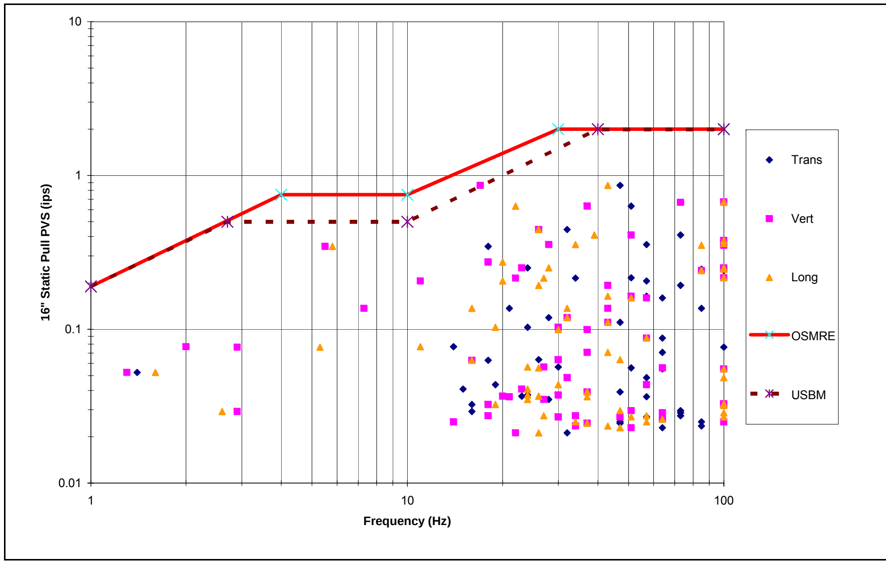


Figure 4 PVS Vs frequency for the static pull burst

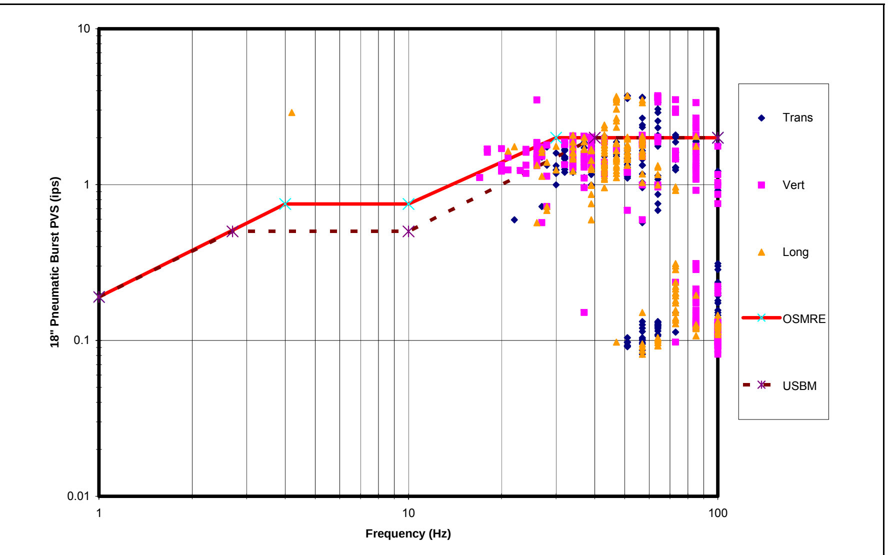


Figure 5 PVS Vs frequency for the 18” pneumatic burst

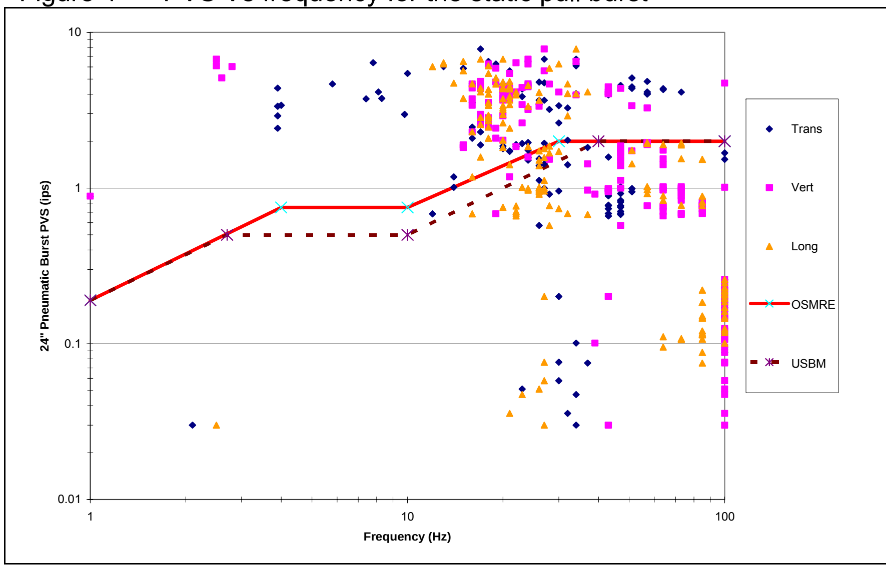


Figure 6 PVS Vs frequency for the 24” pneumatic burst

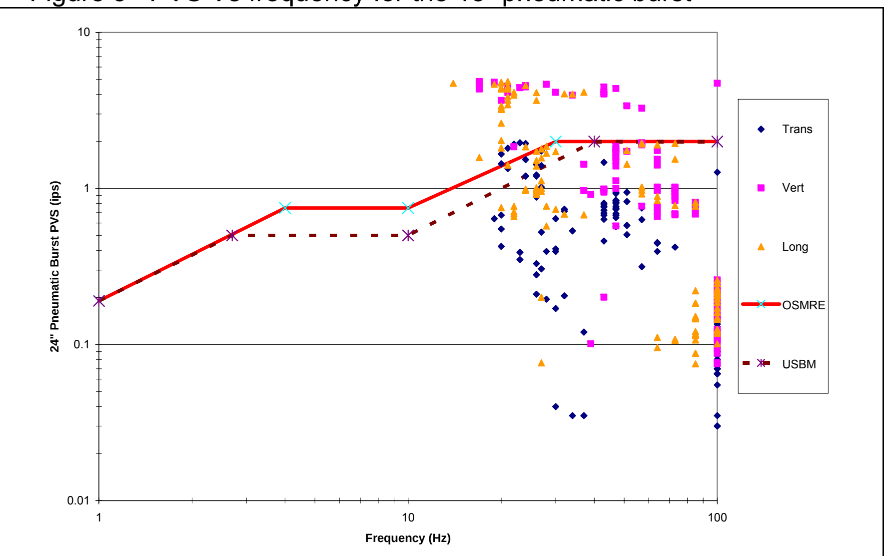


Figure 7 PVS Vs frequency for the 24” pneumatic burst without the piercing portion

placed in a trench dug in rock soil. These concerns are regarding the rock behavior around the pipe and its impact on nearby utilities, pavement, and structures.

The author investigated the ground vibrations associated with bursting small diameter pipes in soft soils and developed guidelines for safe distance from existing nearby utilities, structures, and pavement. However, the ground vibration related to bursting large diameter pipe when the existing trench was dug in rock formations was not thoroughly investigated. The research team at BGSU with the support of the construction and bursting industries attempted to utilize the hard limestone rock of Bowling Green, OH to evaluate these ground vibrations. This paper presents the research methodology, collected data and its analysis, and research conclusion.

EXPERIMENT DESIGN AND RESEARCH METHODOLOGY

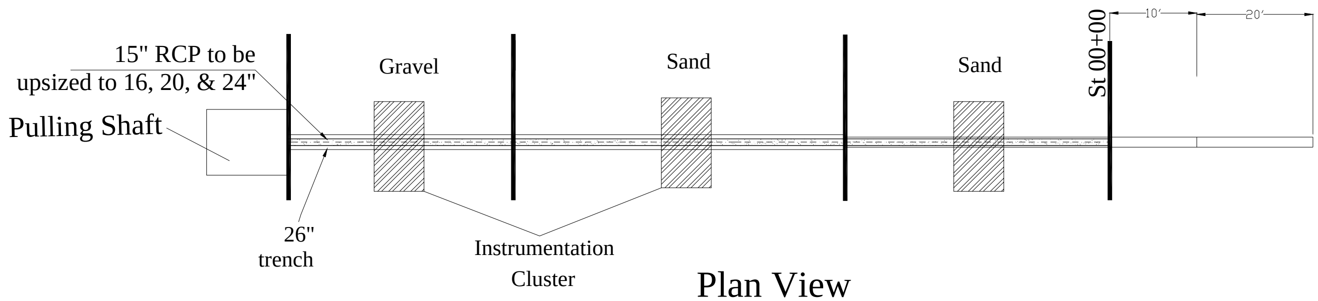
The pipe bursting industry has successfully burst many small diameter pipes with small upsize percentage in rock formations. Therefore, the needed knowledge is more related to larger diameter pipes with high upsize percentage. The bursting industry also acknowledges that if the bursting head is larger than the hard rock trench and able to burst through and break the hard rock, significant damage to nearby structures is more likely to take place.

The researchers designed the experiment to burst three large diameter pipes laid in trenches dug in the hard limestone rock of Bowling Green, Ohio. The experiment consisted of bursting three reinforced concrete pipes (RCP) in trenches with different trench widths and bedding material. Three different upsizing percentages were considered: 12” RCP to 16” HDPE using the static pull bursting system, and 15” RCP to 18” HDPE and 15” RCP to 24” HDPE using the pneumatic bursting system. The three-upsize percentages were 33%, 33%, and 60%. The trench width varied from one with two inch on each side of the bursting head to 6” on each side of the bursting head. Figure 1 presents the site layout and cross section of the test site.

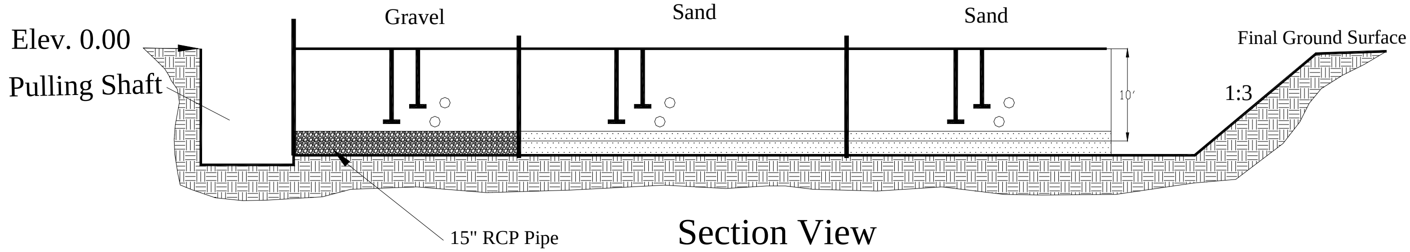
During the construction phase of the test site, Vermeer T-755 Rock Trencher with 26” wide trenching chain was employed to provide accurate and consistent trench width. The 26” trench was backfilled with the excavated rock to trench a second pass at one foot deeper to increase the trench width. The difference in strength between the hard rock on one side and the backfill rock on the other side produced some difficulty in controlling the trencher. The limited availability of the trencher, hardness of the rock, lack of sufficient fund led to some inconsistency in the invert elevation of the northern trench (24 inch burst). The broken edges of the second hand RCP might have complicated the invert and alignment inconsistency. Figure 2 shows the pipe profile of the three sections. On the other hand, this inconsistency might simulate sags and inconsistency in old pipes laid in a rock trench.

During bursting, the ground vibrations were monitored and recorded along with the distance between the bursting head and the vibration monitoring points. Everlert III seismograph from Vibra Tech Engineers was used to monitor the ground vibrations, which allowed the simultaneous recording of data from two three-axis geophones. The data were collected at locations above the centerline and at different offsets from the centerline as presented in Figure 3. Times and bursting head locations were recorded during the bursting every five feet using a watch synchronized to the clock in the seismograph. The collected data from geophone 2 data were consistently low, compared to the data collected from the nearby geophone 1. The researchers decided to ignore the data collected from this geophone to be on the conservative side.

The seismograph was run in only the continuous mode to record vibration data without stopping to reset the seismograph to take another reading. In the continuous mode, data were collected at a rate of 5 to 6 events per minute; each event recorded the Peak Particle Velocity (PPV) in the three directions transverse, longitudinal, and vertical, Peak Vector Sum (PVS), frequency, and velocity time chart.



Plan View

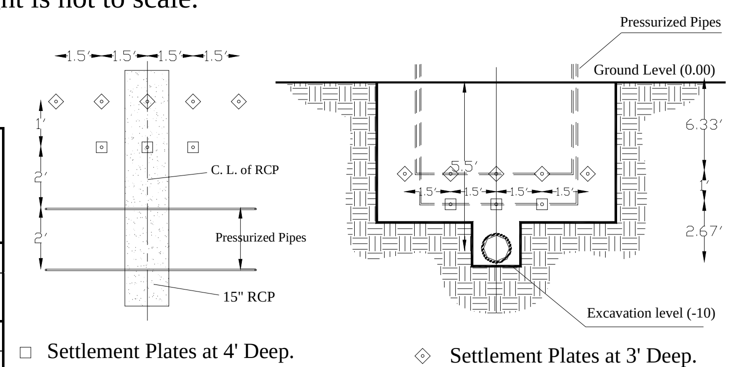


Section View
Drawing height is not to scale.

Notes:

Trench width, pipe upsize, bedding material, and stations for the three bursts are as shown in the table below.

Bursting System	Old Diameter (inch)	Upsized Diameter (inch)	Burst. Head Diameter (inch)	Station		Bedding Material	Trench Width (inch)
				From	To		
Static (South Burst)	12	16	23	0	40	Sand	26
				40	80	Sand	26
Pneumatic (Middle Burst)	15	18	21	0	35	Sand	26
				35	90	Sand	30
				90	145	Gravel	36
Pneumatic (South Burst)	15	24	28	0	35	Sand	36
				35	70	Gravel	52



Instrumentation Cluster Section and Plan

Instrumentation Cluster includes settlement plates and 2" PVC pressurized water lines at distances of 1' and 2' above the existing pipe

Figure 1 The plan and sectional views of the test site in BGSU (The test site consists of three parallel trenches - 20’ apart.)

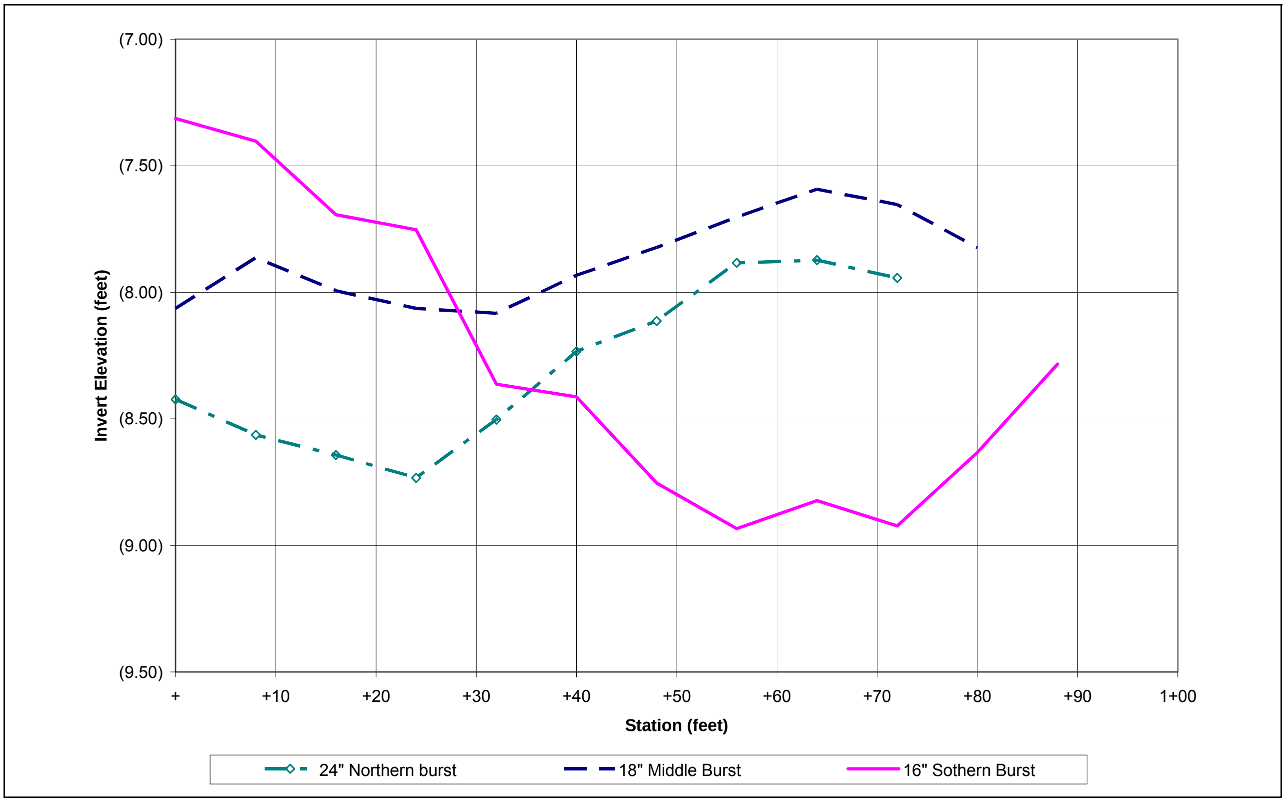


Figure 2 Invert profile of the RCP

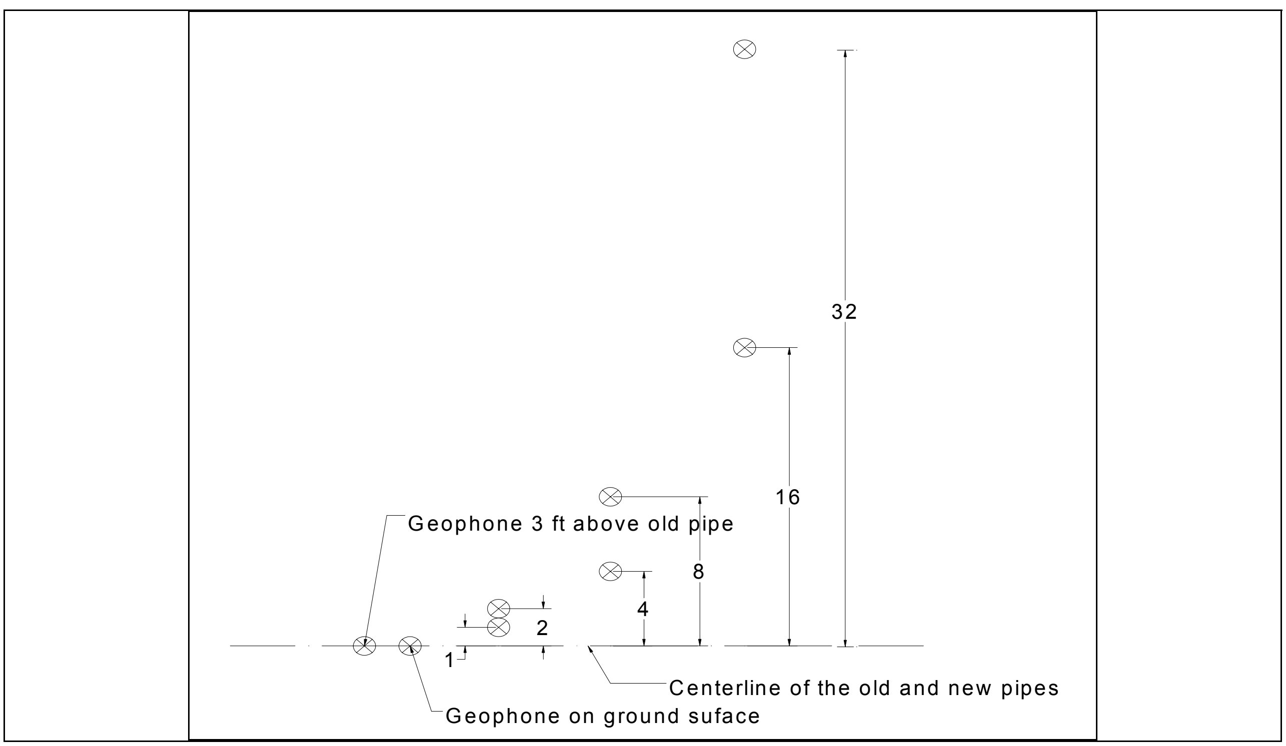


Figure 3 Geophone locations from the centerline of the old and the new pipes in feet

RESEARCH FINDINGS

Figures 4 through 6 present the collected vibration data in terms of PVS Vs frequency for the three bursts. The figure 4 shows that all the points in the static pull burst were below the threshold line established by the United States Bureau of Mining (USBM) and The Office of Surface Mining (OSMRE). These thresholds are the controlling criteria for the onset of cosmetic damage to one or two story residential structures such as the cracking of plaster or wallboard [Dowding 1996]. Figure 5 and 6 show that the majority of the PVS readings were below the above cited envelopes, except a few were above these lines. These few points were recorded at close distance, directly above or at one foot offset from the pipe centerline. During the 24" burst, the bursting head deviated upward from the target path along the pipe centerline. Around station 00+35, the bursting head started to deviate upward, and within a few feet, it was above the pipe piercing its way through the soil instead of bursting the pipe. Potential reason for the upward deviation are the invert inconsistency mentioned earlier which may led to having the cable stuck with pipe rebar or between two pipe joints. As a result, the winch did not pull the head to direct it along the planned path. The rest of the high PVS values were during this piercing phase at close distances from the geophone.

The project included ten pressurized PVC pipes (five at two feet and five at three feet from the old pipe) to simulate a nearby pressurized pipe. These pipes had glued joint right above the centerline of the old pipe to simulate a week point above the bursting operation. All pipes maintained their pressure during the bursts except the one at two feet in the piercing portion where the bursting head was within a few inches from the pipe. The other PVC pipe in that piercing section (about 15" from the bursting head) maintained its pressure. The next section presents discussion of the vibration data analysis to establish the safe distance from the bursting head to nearby utilities, pavement, and structures.

ANALYSIS PROCEDURES

The vibration data were evaluated under the assumption that the PPV component at each vibration event has an inverse relationship with the scaled distance from the bursting head. Any of the following equations mathematically represents this relationship:

$$\text{Log (PPV)} = C_1 + S \text{ Log (D)} \quad \text{or} \quad PPV = C_2 \cdot (D)^S \qquad \text{(Eq 1)}$$

Where C_1, C_2, and S are constants and D is the scaled distance between the bursting head and the monitoring point. S is the slope of the relationship line between log of PPV and log of D; S is negative. C_1 is the PPV at a distance of one unit (Atalah 2003). The objective of this portion of the research is to establish the values of C and S or their potential ranges when bursting in hard surrounding soils. This allows the estimation of the safe distance for buried pipelines, surface structures, or pavement from the bursting head. The cut off distance can be estimated based on a controlling PPV or a controlling PPV/frequency chart provided the nearby structures be in sound structural conditions. The cut-off standard employed throughout this paper is based on the USBM and the OSM PPV-frequency envelopes. A controlling limit of PPV can be established based on the type and status of the structure.

The data collected during the bursting for each job were tabulated in a spreadsheet. For each event, the distance between the bursting head and the geophone were calculated and added to the spreadsheet. The highest PPV and its direction, PVS, and frequency were also added to the spreadsheet. The bursting head position for each event was calculated through interpolation of the time/station log. The geophone position for each event was recorded with all the relevant information such as depth, trench width, etc. The data analysis continued by plotting PVS against the distance from the bursting head on a log/log scale. Regression analysis between log of the diagonal distance between the bursting head and the geophone and log of the PVS was conducted to calculate the regression parameters such as Sum Squares of Errors (SSE), Total Sum of Squares (SST), correlation factor, slope, intercept, 95% prediction interval (PI), etc. Figures 8 and 9 present the 95% Prediction Interval upper limit (PI) and the regression line together with the data points on a log/log scale for the 18" and 24" bursts.

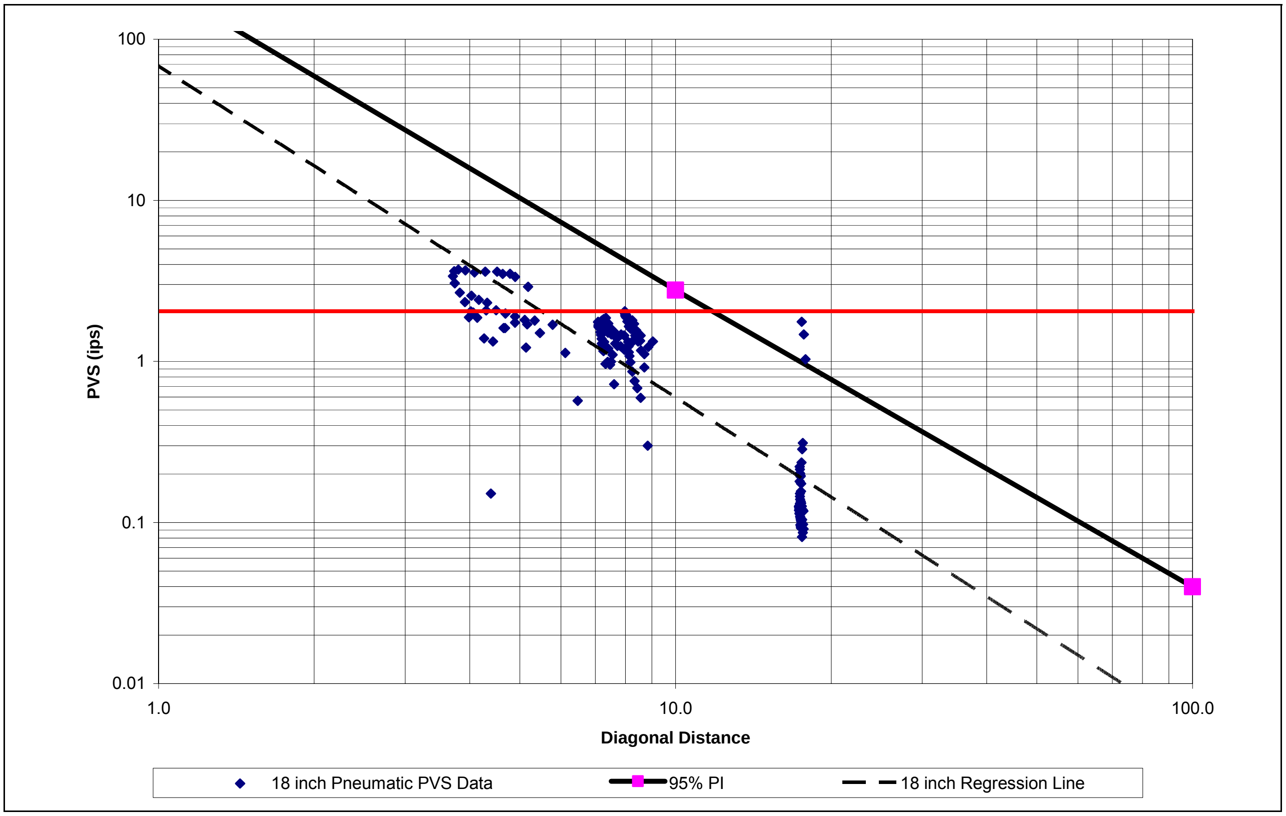


Figure 8 PVS Vs distance for the 18” pneumatic burst

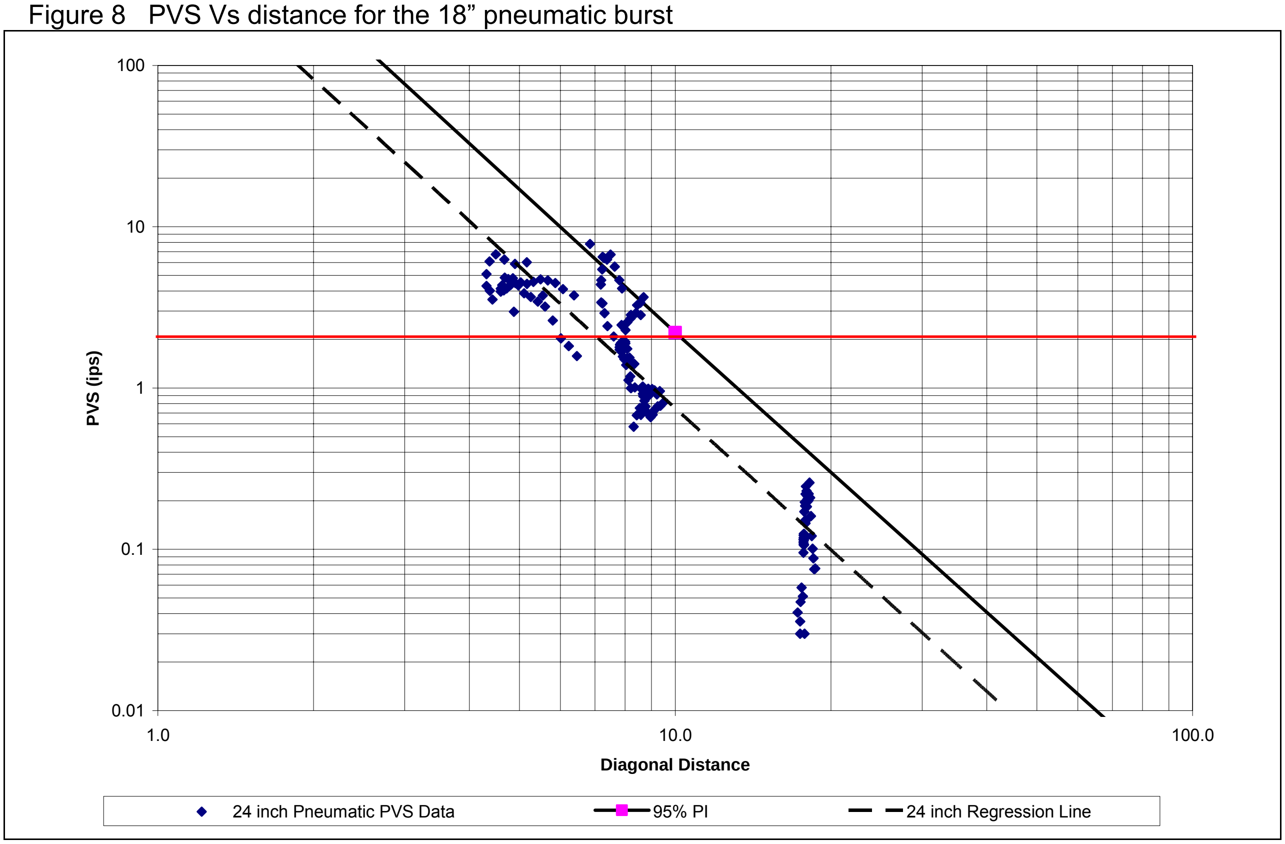


Figure 9 PVS Vs distance for the 24” pneumatic burst without piercing portion

Many American and Canadian investigators recommend a safe level of 2 inch/second for residential buildings and Sweden investigators recommend 3 inch/second for construction blasting [Wiss 1980]. Dowding [1996] reported that buried structures could withstand particle velocities far in excess (at least 5.5 to 8.5 inch/second) of the typical 2 inch/second cautionary level. The PPV control limit for pipelines and buried structures can be safely assumed at 5 inch/second unless the existing pipeline is in poor structural condition. For buildings and pavements, it can be safely assumed as 2 inch/second. As with any analytical prediction used in geotechnical engineering, the results are most effective as an aid to engineering judgment and experiences [Chapman et al 1996].

The statistical analysis showed that there is a high correlation between the log of the distance from the bursting head and the log of the PVS in the pneumatic bursting. The correlation coefficients for the 18" and the 24" bursts were -0.76 and -0.93 respectively. In conditions similar to that of the test, the 95% upper limit Prediction Interval (PI) for the 18" and 24" bursts in Figures 8 and 9 indicate the following guidelines:

- There is a 95% probability that residential structures are safe at a distance of 11 feet or more from the bursting head because the 95% PI line intersects the safe limit for residential structures of 2 inch/second at 11 feet.
- There is a 95% probability that commercial structures are safe at a distance of 8.5 feet or more from the bursting head because the 95% PI line intersects the safe limit for commercial structures of 4 inch/second at 8.5 feet.
- There is a 95% probability that buried structures are safe at a distance of 7.5 feet or more from the bursting head because the 95% PI line intersects the safe limit for buried structures of 5 inch/second at 7.5 feet.

On the other hand, the correlation between the log of the distance from the bursting head and the log of the PVS in static pull case is very weak (correlation coefficient ≈ 0). Therefore, conclusion about the safe distance from the bursting head cannot be drawn. In the mean time, all the recorded PVS points were below the threshold envelopes of the OSM and USBM. Ground movement points at different distances were monitored and recorded during the test and the project report discusses these findings in detail.

CONCLUSIONS AND RECOMMENDATIONS

Pipe bursting is a proven method of replacing and upsizing underground utilities safely and economically. The inherent cost advantages of pipe bursting over open-cut replacement, particularly when digging in hard rock, are significant. While ground vibrations may be quite noticeable to a person standing on the surface close to a pipe bursting operation, the levels of vibrations are unlikely to damage nearby structures except at very close distances.

The overall finding is that ground vibrations at short distances from the bursting operation quickly fall to levels that will not cause even cosmetic damage to buildings. The tolerance of buried pipelines to vibration is typically much larger.

Pipe bursting small diameter pipes with small upsize percentage is relatively safe even at close distance of seven feet [Atalah, et Al 1998]. Most residential structures are further than seven feet from any main utility line. Even for bursting lateral connections to residential structures, the bursting systems require a small excavation for the pulling cable/rod. This excavation provides enough safeguard from the small bursting operation.

Pipe bursting large diameter pipes with high upsize percentage when the old pipe is placed in a rock trench provides a higher level of ground movements that require a longer safeguard distance from the bursting head. A safe distance of eleven feet is recommended in these conditions if the nearby structure is in sound structural condition. Large diameter pipes are mostly main lines installed in the right of way, which is usually far from the residential or commercial buildings. The main lines are also deeper than the lateral connections, which provide additional safeguard distance from the bursting operation. All nearby pressurized PVC pipes even as close as two feet from the old pipe and 15 inches from the bursting head endured the bursting action. In addition, the statistical analysis indicates that the safe distance should be more than 7.5 feet from buried structures. Nearby utilities and buried structures closer than 7.5 feet may require a small excavation in the bursting path to shield these structures from the vibration.

The statistical analysis indicates that there is no correlation between the distance from the bursting head and the level of vibration in the static pull systems. We could not compare the PVS from the static pull system and that from the pneumatic system because the diameter and upsize percentage were different. If the ground movement from the static pull system is smaller than that from a pneumatic system, we may be able to burst closer to building and utilities using this system. Therefore, other analytical means should be sought to provide the needed guidelines.

Further research to establish guidelines for the safe distance from a piercing tools operation is needed because the safe distance might be much shorter than expected.

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