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SYNOPSIS This paper presents a case in which dynamic compaction (DC) was used as site preparation for a proposed supermarket. The site was located immediately adjacent to a steep, 15 ft. high slope leading down to the Hudson River. Test borings revealed subsurface conditions consisting of uncontrolled miscellaneous fill extending 10 ft. below river level. Stability evaluations indicated that the slope was unstable under rapid drawdown conditions, and placement of the supermarket at the crest of the slope further decreased its stability. There were also concerns regarding possible differential settlement of the supermarket due to the variability of the fill. Dynamic compaction was selected as a cost-effective way to create a more uniformly dense foundation material, and to improve the factor of safety against deep seated slope failure. Verification test borings were performed after both the first and second DC passes. Vibration data obtained during monitoring of the DC program is presented.

INTRODUCTION

In early 1990, Hannaford Bros. Co. proposed the construction of a new Super Shop'n Save Supermarket at the intersection of 126th Street and 2nd Avenue in Troy, New York (refer to Figure 1, Site Plan). The approximately 4-3/4 acre site was bordered by the Hudson River to the west. A 67,000 sq. ft. one and two story building formerly occupied the site. Most of the site was level with grades ranging from approximately El. 26 to El. 30. Elevations are in feet and are referenced to National Geodetic Vertical Datum minus 4.8 ft.

The riverbank slope was approximately 15-ft. high, heavily wooded, and ranged from approximately 2 horizontal to 1 vertical (2H:1V) to 3H:1V. Localized steeper areas (1.5H:1V) were also present. Normal Hudson River level was El. 17.7, but had recently been observed to be as low as El. 10.9. The 100-year flood level was El. 30.2.

The proposed development called for demolition of the existing structure and construction of the 45,000 sq. ft. supermarket. Proposed floor grade was El. 33.8. Paved parking and truck access areas were proposed at the front and rear of the facility. As indicated on Figure 1 and on the schematic section shown in Figure 2, the proposed supermarket was located at the crest of the steep slope leading down to the Hudson River.

SUBSURFACE CONDITIONS

Subsurface explorations conducted at the site consisted of twenty-eight test borings

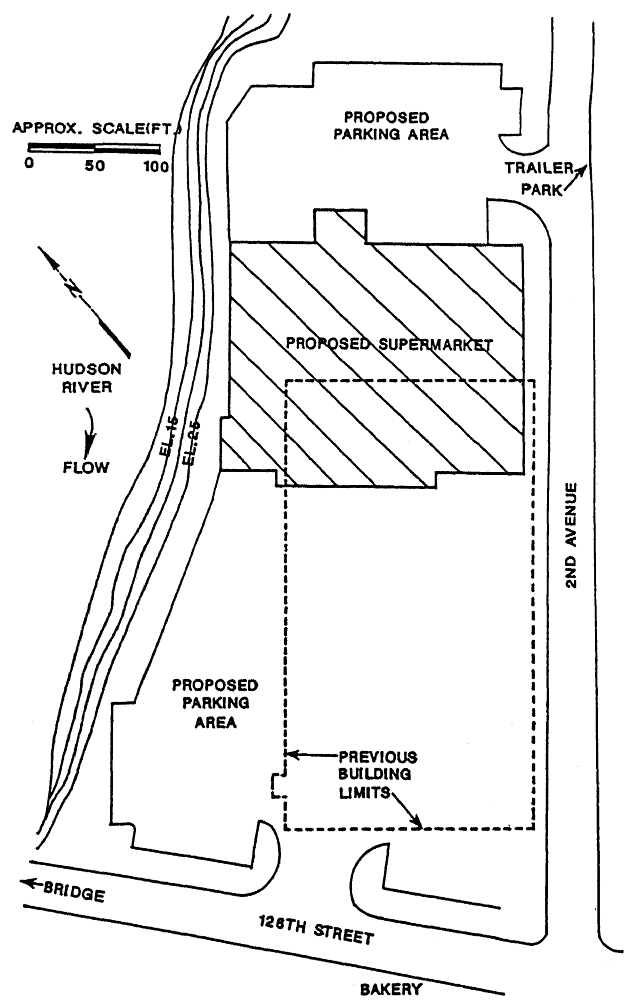

Fig. 1. Site Plan

and five groundwater observation wells. Standard penetration tests (SPT's) were conducted in each boring at 5-ft. intervals by driving a 1-3/8 in. I.D. split-spoon sampler (no internal liner) using a 140-lb. safety hammer dropped a distance of 30-in. The hammer was raised using 2 turns of the rope over a cathead.

Soil conditions consisted of miscellaneous fill and relatively minor thicknesses of naturally-deposited alluvium and dense glacial till overlying bedrock. Miscellaneous fill was encountered in thicknesses ranging from 1 to 27 ft. The greatest thicknesses of miscellaneous fill were encountered near the crest of the riverbank adjacent to the Hudson River, and extended up to approximately 10 ft. below river level. The fill was described as dark brown, medium to fine SAND, with variable amounts of silt, glass, brick, ash, cobbles, rubber, concrete, mortar, coal and roots. The range of miscellaneous fill gradation based on the results of laboratory testing is shown on Figure 3. Water levels at the site typically matched Hudson River level or were approximately 1 to 2 ft. above bedrock. A typical subsurface profile at the riverbank is shown on Figure 2.

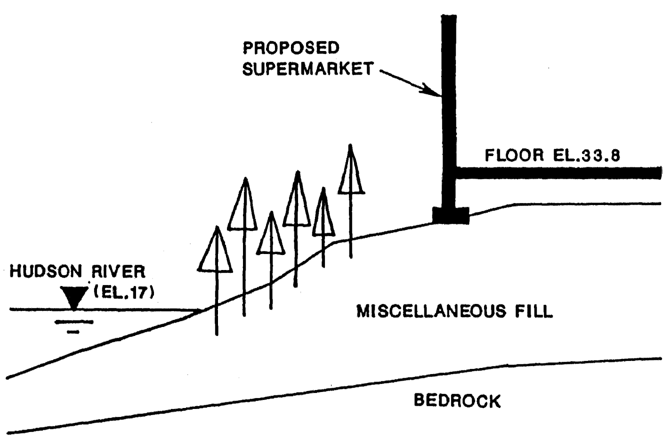

Fig. 2. Schematic Cross-Section Of Slope

STP N-values within the miscellaneous fill were corrected to account for borehole diameter, hammer and lifting energy, rod length, sampling tube and overburden using the methodology described in Kulhawy and Mayne (1990). Corrected SPT N-values $(N_1)_{60}$ are plotted versus elevation in Figure 4, and typically ranged from 10 to 20 blows per ft. The average $(N_1)_{60}$ was about 16.

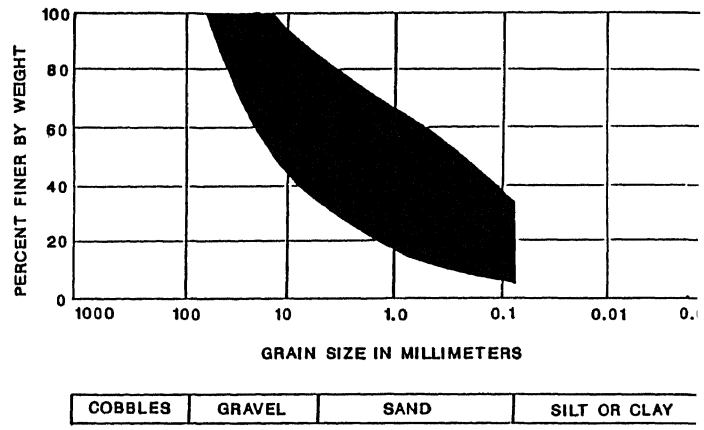

Fig. 3. Range Of Miscellaneous Fill Gradation

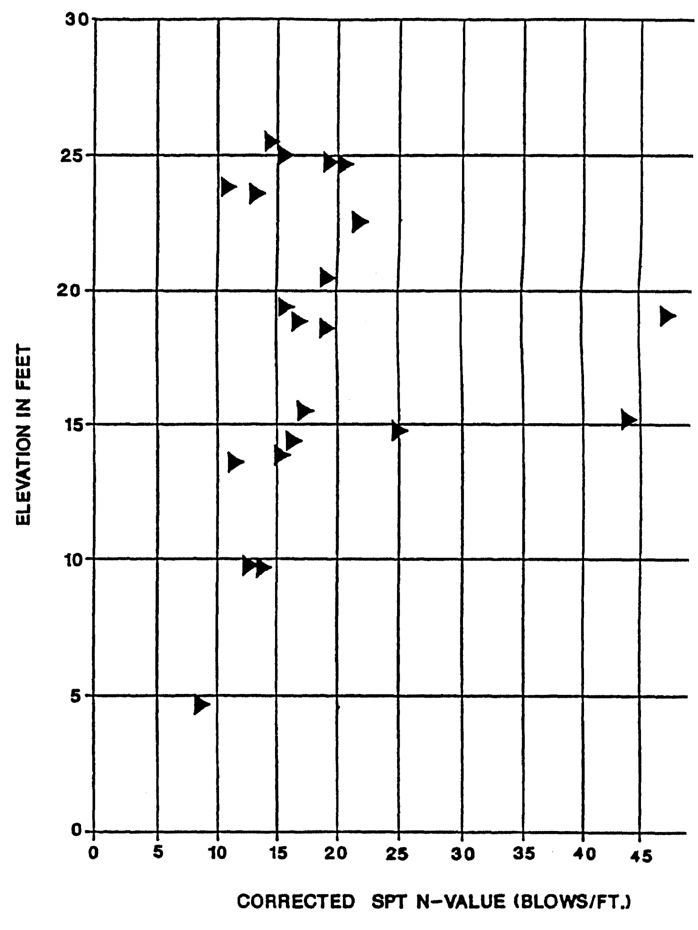

Fig. 4. Corrected SPT N-Value Versus Elevation

EVALUATION

The Super Shop'n Save Supermarket was designed with column spacings up to 65-ft. wide, column loads up to 250,000 lbs., and relatively heavy floor loads due to the weight of the shelves and product loading. It was critical that no cracking of the floor occur since cracking would be highly visible and a maintenance problem. The miscellaneous fill was not considered to be suitable for direct foundation support due to its uncontrolled nature and variable composition. The floor was considered to be susceptible to cracking if constructed as a slab-on-grade due to the potential for soft or loose zones.

Since the proposed supermarket was located immediately adjacent to the crest of the riverbank, slope instability could cause significant damage to both the supermarket and its surrounding paved areas. Therefore, slope stability was an important design issue. The variable composition of the miscellaneous fill made determination of strength properties difficult. Sophisticated laboratory shear testing was not considered appropriate because of problems in obtaining representative samples. Direct correlation with field SPT data was judged to be the most appropriate method for determination of strength properties.

As indicated in Kulhawy and Mayne (1990), the original studies tried to correlate SPT N-value directly with internal angle of friction. Early correlations include Meyerhof (1956) and Peck, et. al. (1974), and are summarized as follows:

TABLE I. Comparison of Early Correlations Between SPT N-Value and Friction Angle

SPT N-Value Range (blows/ft.)	Friction Angle (Degrees) Meyerhof (1956)	Friction Angle (Degrees) Peck, et. al. (1974)
0 - 4	less than 30	less than 28
4 - 10	30 - 35	28 - 30
10 - 30	35 - 40	30 - 36
30 - 50	40 - 45	36 - 41
Greater than 50	Greater than 45	Greater than 41

Source: Kulhawy and Mayne (1990), p. 4-15

Use of the Meyerhof correlation and an average $(N_1)_{60}$ value of 10 to 20 blows per ft. suggested that the internal angle of friction was at least 35 degrees. However, the Meyerhof (1956) correlation was judged to be potentially unconservative for silty sand. The more conservative Peck et. al. (1974) correlation suggested an internal angle of friction of approximately 32 degrees. Use of the Peck et. al. (1974) correlation appears to be the more widely accepted method (Kulhawy and Mayne, 1990).

More recent work revealed that the correlation between SPT N-value and friction angle also depends on stress level and other factors. Schmertmann (1975) presented correlations which included stress level. However, use of the Schmertmann (1975) correlation does not appear to be appropriate for silty sand. Use of the various published correlations which incorporate relative density were not appropriate since the fines content of the miscellaneous fill was generally greater than 15 percent. Due to the high degree of compositional variation in the miscellaneous fill, an internal angle of friction of 32 degrees was selected based on Peck et. al. (1974) for the existing condition.

Slope stability evaluations were performed for the condition with the supermarket founded on spread footing foundations and located at the crest of the riverbank using the computer program GEOSLOPE (originally developed at Purdue University). Failure surfaces were analyzed using both the Modified Bishop Method of Slices and Janbu Block methodologies. Results of slope stability evaluations revealed that the slope was only marginally stable under normal operating conditions, and would fail under the condition of rapid drawdown following the 100-yr. flood. In discussions with the owner it was agreed that an appropriate design criteria would be a factor of safety of 1.0 against rapid drawdown from the 100-yr. flood. Surficial portions of the riverbank would be allowed to fail under this condition provided that the supermarket was not damaged. Since the Hudson River Floodplain included the riverbank, project permits would not allow the riverbank or its vegetation to be impacted by construction. The vegetation provided a visual barrier and had a beneficial impact on the surficial slope stability.

DYNAMIC COMPACTION

Several site remediation/preparation alternatives were evaluated including excavation and replacement of the miscellaneous fill within the limits of the proposed building and area of influence below foundations, and deep foundations. The excavation and replacement alternative would have involved excavations up to 25 ft. deep, and extending up to 10 ft. below river level. Removal and replacement of the entire riverbank would have been an unavoidable consequence. Deep foundation systems such as pile support and a structural slab might have eliminated concerns relative to foundation support, but would not have addressed the inadequate slope stability. It was clear that an appropriate solution to the above problems would have to address both the foundation support and slope stability issues simultaneously.

Installation of stone columns was considered as a possible solution since it improved both slope stability and foundation support. However, the stone column solution was not selected for economic reasons. The combination of DC, a shallow foundation system and placing the exterior wall footing closest to the riverbank 10 ft. below ground surface was selected as a cost-effective solution which addressed both foundation support and slope stability issues. Placement of the footing closest to the river 10 ft. below ground surface would allow upper portions of the slope to move under less extreme conditions without damaging the supermarket. This footing was designed as a retaining wall assuming no passive pressure on the outside of the wall (i.e. assuming that failure of the fill outside the wall had already occurred during the rapid drawdown condition). DC created a more uniformly dense foundation subgrade material suitable for direct support, and improved slope stability against the deep failure surfaces which could effect the footing located closest to the river. A schematic section of the solution is shown on Figure 5.

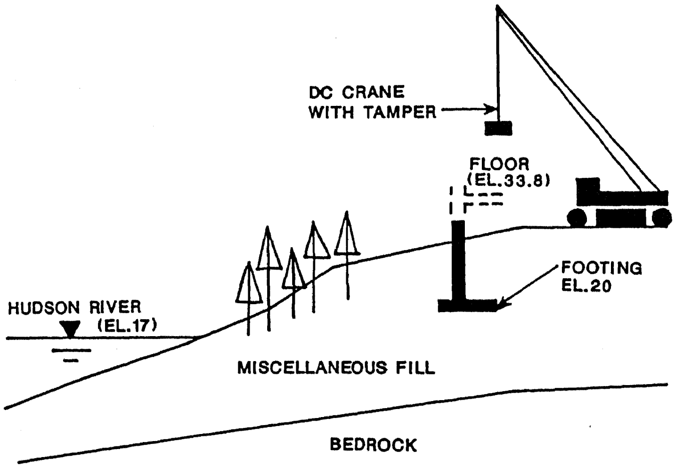

Fig. 5. Schematic Cross-Section Showing Solution

DC was performed in the areas indicated on Figure 6. These areas included the portion of the proposed building area where thicknesses of fill exceeded approximately 5 ft., and within an approximately 20-ft. wide strip along the crest of the riverbank. The DC program consisted of dropping a 10-ton weight from heights ranging from 25-ft. to 80-ft., 4 to 8 times per impact point, per pass, on a 6-ft. grid pattern. Two passes were made. After each pass, the area was levelled and rolled with a large self-propelled vibratory roller. The first pass lowered the site by approximately 12-inches; the second pass lowered the site an additional 6 to 8 inches.

Verification test borings were drilled following both the first and second passes to evaluate the degree of densification achieved. Corrected SPT data prior to DC, and after the first and second DC passes is presented in Figure 7. Based on a review of SPT data after the second DC pass, SPT N-values typically ranged from 20 to 50 blows per ft.; most of the SPT N-values were above 25 blows per ft. Using the Peck et. al. (1974) correlation, a post-DC friction angle of 35 degrees was achieved. This provided the required 1.0 factor of safety against deep seated slope failure for rapid drawdown following the 100-yr. flood.

VIBRATION MONITORING

Limiting vibrations at nearby structures was a primary goal during DC. Project specifications called for a maximum particle velocity of 0.5 in. per sec. at all nearby structures, and 0.25 in. per sec. at "special interest" structures judged to be either of critical importance or potentially susceptible to damage due to vibrations. Special interest structures are shown on Figure 6 and included the 126th Street Bridge, a bakery and a nearby trailer park. These structures were located approximately 65 ft., 160 ft., and 180 ft. from the nearest impact point, respectively.

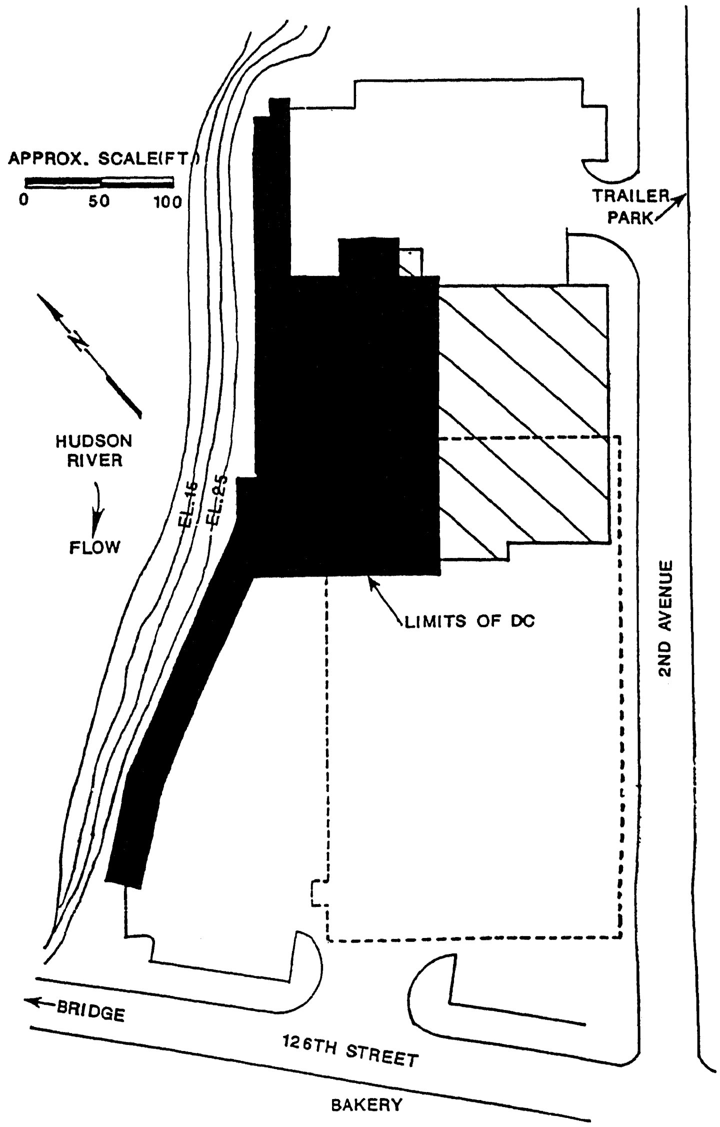

Fig. 6. Limits of DC

Predictions of vibration levels were made during design based on data presented by Lukas (1986). Due to the proximity of special interest structures to some of the DC areas, predicted vibration levels generally exceeded specification limits. Therefore, a DC vibration test program was conducted prior to production DC to develop site-specific scaled energy vs. peak particle velocity data. The DC test program provided a more accurate prediction of vibration levels and resulted in lowering the drop height to 25 ft. in the vicinity of the bridge.

Four seismographs were used during the test program and production DC to measure vibration levels at the site. The seismographs were typically placed at the nearest special interest structure, and between the DC operation and the other special interest structures. Pre- and post-DC condition surveys of all nearby structures were made; no damage resulting from DC was detected. A plot of measured vibration levels versus scaled energy, including both DC test program and production data, are presented on Figure 8. Measured frequencies of vibration typically ranged from 10 to 25 Hz; the average frequency was approximately 15 Hz.

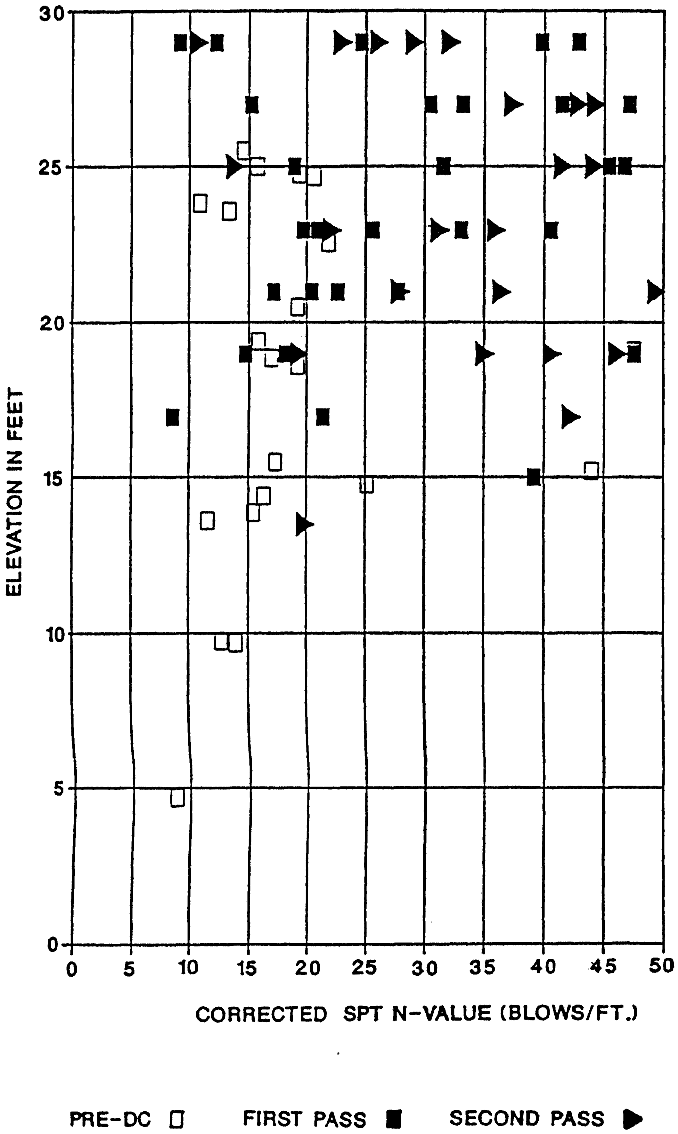

Fig. 7. Corrected SPT Data Prior To DC

Vibration data indicated on Figure 8 show an increase in particle velocity from the first pass to the second pass. This reflects the increase in miscellaneous fill density between the first and second passes. Figure 9 presents data showing that particle velocities increased with successive impacts at the same location.

CLOSURE

This paper presented a case in which DC was used as site preparation and to improve slope stability against the deep failure surfaces which could affect the proposed supermarket. It is an example of the effectiveness of the new soil improvement methodologies which have recently been developed.

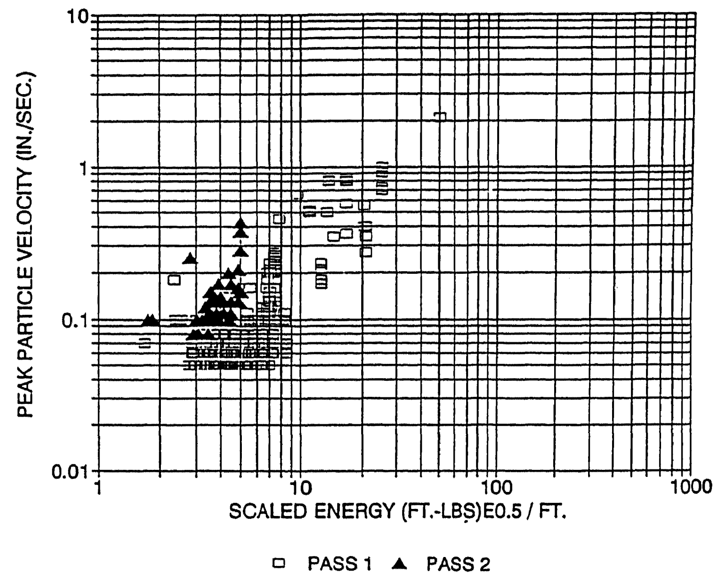

Fig. 8. Vibration Monitoring Data

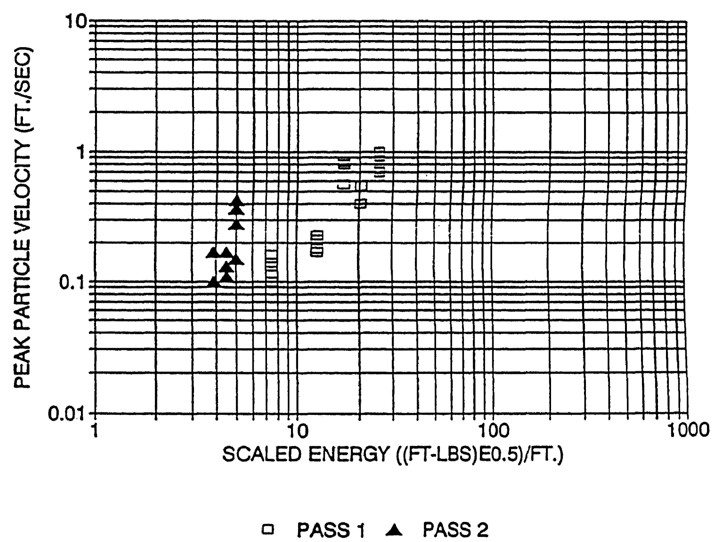

Fig. 9. Vibrations From Successive Impacts At The Same Impact Point

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