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L. P. Jedele

Soil and Materials Engineers, Inc., Livonia, MI

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Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. 11.8

Pile Driving Criteria for Construction Near an Historic Dam

L.P. Jedele
Geodynamics Consultant, Soil and Materials Engineers, Inc., Livonia, MI

SYNOPSIS: The construction of a new road included a bridge crossing a river. The location of the bridge crossing was about 300 feet (91.5 meters) downstream from an historic dam. Prior to construction, concerns were raised about vibrations which might be generated from construction activities, especially pile driving for the new bridge abutments, and their potential effect on the integrity of the dam. As a result, a vibration study was conducted on the dam, prior to construction, to assess the vibrations generated from normal operation of the dam and from a simulated pile driving operation. Based on the simulated pile driving activity, a recommendation was made for limiting the pile driving energy, which was implemented during construction. A follow-up vibration study was conducted in the field during construction to both monitor the vibrations transmitted to the dam and adjust pile driving operations (if needed); and to confirm the data collected from the previous investigation.

INTRODUCTION

The Secord Dam is located on the Tittabawassee River about 10 miles (16.1 km) northeast of Gladwin, Michigan. The dam consists of a concrete spillway with two control gates, contiguous earth embankments, and a powerhouse used by the Owner. The dam was originally constructed in 1924 and is reported to bear on a clay hardpan material. About 11 years after completion of the dam, sheet piling was driven into the upstream side of the earth embankments, extending into the underlying clay hardpan, to reduce seepage.

In 1986, the County Road Commission was planning to construct a new county road which would cross the Tittabawassee River about 300 feet (91.5 m) downstream from the existing dam. The structure crossing the river was to consist of a three-span bridge with concrete abutments on both sides of the river. The two center supports were to consist of piers constructed within the river channel. As much as 35 feet (10.7 m) of engineered fill would be required to achieve the proposed bridge deck elevations along the abutment.

Since driven piles were being considered for support of the proposed bridge abutments, there was concern on the part of the Owner that vibrations which would be created by the pile driving operation might damage the dam. Soil and Materials Engineers, Inc. (SME) recommended that vibrations in the vicinity of the site be monitored prior to driving of production piles in the field. This recommendation was acceptable to the County Road Commission and, therefore, this investigation was divided into two primary work efforts:

1. **Phase I** - monitor vibrations during typical dam operation activities, gather data regarding potential vibrations generated from pile driving for the proposed bridge, prior to construction, and develop pile driving criteria for construction; and
2. **Phase II** - monitor vibrations generated from the actual pile driving operation associated with construction of the new bridge as a means of verifying a safe level of vibrations based on pile driving energy criteria developed from Phase I.

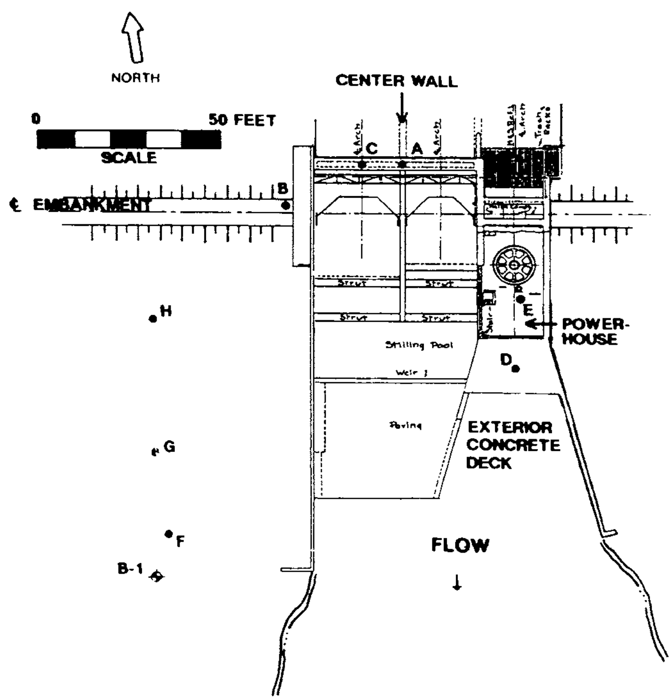
PHASE I INVESTIGATION

The Phase I investigation involved field vibration measurements to determine vibration levels from normal dam operations and the effect that a simulated pile driving operation would have on Secord Dam. The vibration levels observed from dam operations provided background information to be used for comparison during pile driving activities. The simulated pile driving operation was used in combination with a scaled distance analytical approach as a means of determining a recommended maximum, not to exceed, energy for the pile hammer to be used during installation of the bridge abutment piles.

Vibration Measurements

Vibration measurements were taken on December 9, 1986 by the author. Measurements were made with vertical and horizontal velocity geophones wired into a Honeywell Fiber Optic Oscillograph, Model 1858 and permanently recorded on special light-sensitive paper.

The geophones were placed at the locations given by the alphabetically labeled symbols on the Figure 1 location plan. All the monitoring locations A through I were situated on either the surface of the dam or ground surface of the adjacent earth embankment. Specifically, location A was on the crest of the center wall separating the two sluice control gates. Location B was on the crest of the earth embankment about 3 feet (0.91 m) west of the concrete dam. Location C was on a concrete slab walkway, measuring 3 feet (0.91 m) wide x 23 feet (7.0 m) long x 15 inches (0.38 m) thick, spanning over the west control gate. Locations D and E were at the floor of the powerhouse, with location D on an exterior concrete deck slab and location E in the powerhouse about 3 feet (0.91 m) south of the generator. The remaining monitoring points F through I were on the ground surface at the indicated locations.



LEGEND

●[A] VIBRATION MONITORING POINT

⊕B-1 SIMULATED PILE DRIVING TEST LOCATION

FIGURE 1

LOCATION PLAN OF SECORD DAM VIBRATION MONITORING POINTS AND SIMULATED PILE DRIVING TEST (1m = 3.28ft.)

Vibration Analysis and Results

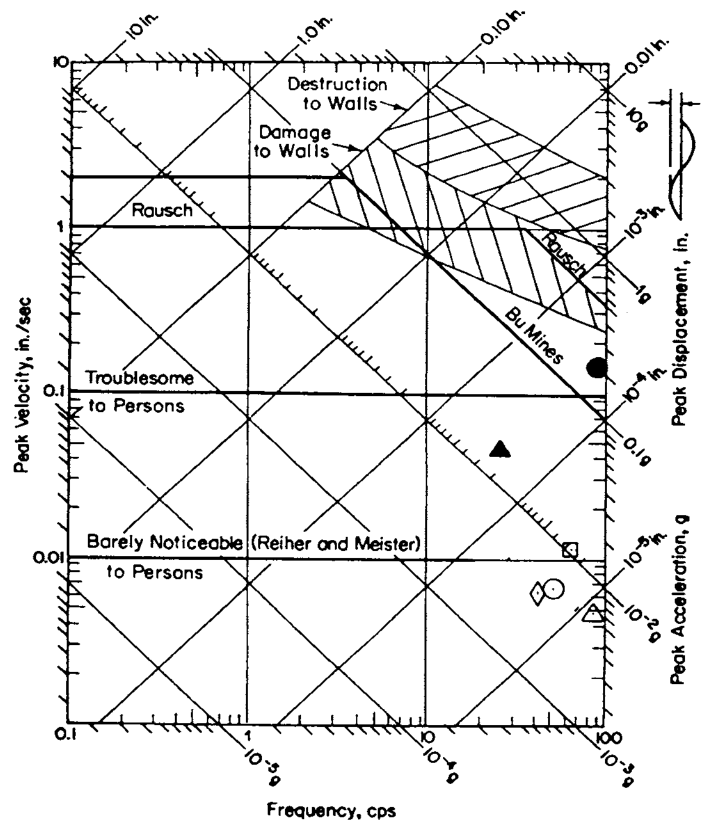
Based on the analysis of the records, the indicated maximum vertical and horizontal peak velocities in inches per second (1 ips = 25.4 mm/sec) with corresponding vibration frequency were computed. A summary of the main dam operating activities and maximum measured vibration levels are given as follows:

TABLE 1

MAXIMUM MEASURED PEAK PARTICLE VELOCITY IN IPS
(1 ips = 25.4 mm/sec)

EVENT	LOCATION A	LOCATION B
Ambient	0.00037	0.00051
Generator On	0.0066	0.0048
Open/Close Gates	0.16	0.044

The information in this table illustrates th progressive increase in vibration level as mor activities occur. The ambient represents th so-called "at rest" or no activities condition When the generator was operating, the vibration increased at least one order of magnitude abov the ambient levels. We also found the openin or closing of the control gates to be the condi



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MAXIMUM VIBRATION WHEN GENERATOR RUNNING:
⊙ LOCATION "A" △ LOCATION "B"
⊡ LOCATION "C" ◊ LOCATION "D"

MAXIMUM VIBRATION - OPENING OR CLOSING GATES:
● LOCATION "A" ▲ LOCATION "B"

FIGURE 2

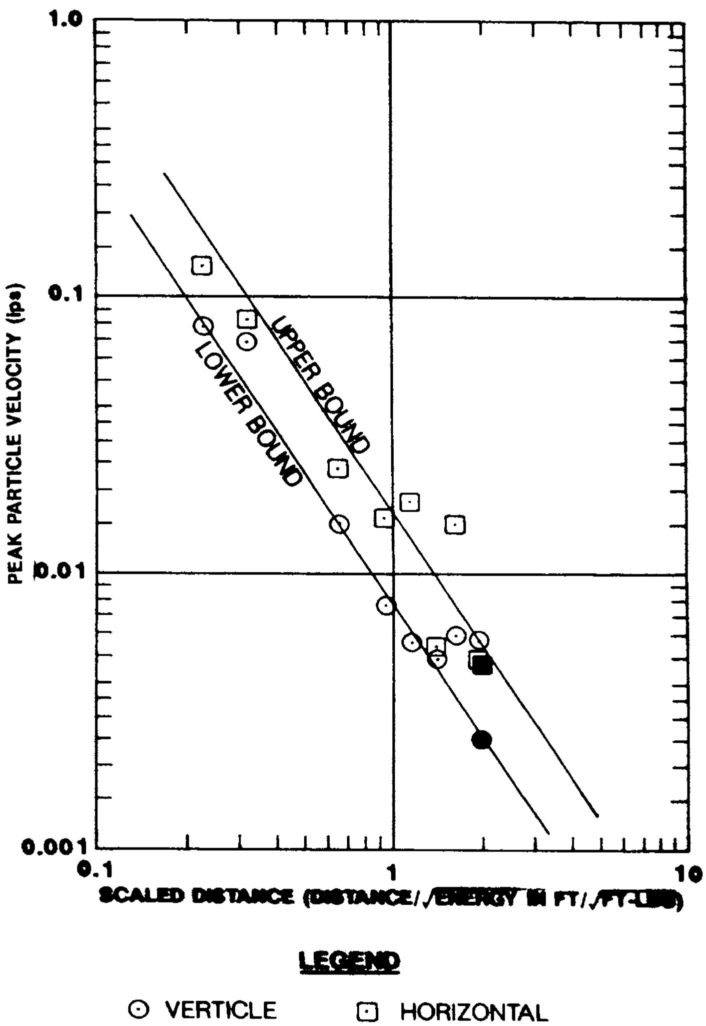
MAXIMUM VIBRATION LEVELS MEASURED ON OR ADJACENT TO SECORD DAM ON 12/09/86 (1in = 25.4mm) (CHART AFTER RICHART ET AL) tion which appeared to generate the highest vibrations. Such vibrations resulted from a momentary (transient) impact when the sides of the gate "hung-up" along the confining concrete wall or when the chain which opened or closed the gates jumped a sprocket.

These results are superimposed on the Figure 2 graph which illustrates the generally accepted vibration criteria of structural and subjective response. As shown by the shaded symbols, the maximum vibrations occur from opening or closing the control gates, and fall within the "Easily Noticeable to Troublesome to Persons" range. The open symbols, representing maximum vibrations measured from the generator operating, fall in the "Not Noticeable to Persons" category, below 0.01 ips (0.254 mm/sec).

Even though this criteria is traditionally used for modern structures in good condition, it appears to be reasonable in light of the criteria proposed by Konon and Schuring for historic and sensitive older buildings. Their criteria is a damage threshold for historic and sensitive older structures. The criteria is a peak particle velocity of 0.25 ips (6.35 mm/sec) for frequencies up to 10 Hz and 0.50 ips (12.7 mm/sec) for frequencies greater than 40 Hz. For frequencies in the 10 to 40 Hz range, the peak particle velocity varies linearly (on a log-log plot) from the 0.25 to 0.50 ips (6.35 to 12.7 mm/sec) level. On this basis, the vibration levels measured from normal operation of the dam are below the threshold levels proposed by Konon and Schuring.

The simulated test pile was located at designation "B-1" as shown on Figure 1, approximately 110 feet (33.5 m) downstream from the centerline of the earth embankment. The simulated pile driving procedure involved augering a hole through the overlying soils into the clay hardpan, inserting a 4-inch (10.2 cm) diameter closed-end casing into the hole and driving the casing with a 300 pound (136.1 Kg) hammer dropped from heights of 5 or 10 feet (1.52 to 3.05 m). Based on monitoring vibrations, from the simulated pile driving, at Locations A, B and E, while the generator was in operation, we found no significant change in the vibration levels from those measured when the generator alone was operating. Specifically, at Location A the maximum peak particle velocity was 0.0072 ips (0.18 mm/sec) and at Location B it was 0.0048 ips (0.12 mm/sec). Since the vibration levels were not affected by the simulated test pile at location "B-1" (which was the closest planned location to the dam), two other previously planned simulated pile locations were not tested.

In association with the simulated pile driving test, it was desirable to obtain attenuation data, i.e., distance vs. vibration level and relate it to energy from the hammer impact. By referencing the location of the simulated test pile (B-1) to monitoring locations F through I, all of the peak particle velocity values range in a normal and expected relationship consisting of decreasing vibration levels with greater distances from the source of vibration. This relationship is illustrated by the log-log plot of peak particle velocity vs. scaled distance on Figure 3. Scaled distance is the distance from the simulated pile to the monitoring point divided by the square root of the impact energy exerted by the hammer. Energy levels of 1,500 and 3,000 ft-lbs (2,035 and 4,070 N-m) were used in the field for this evaluation. The graph shows a band-width or upper and lower bound range of peak velocity over scaled distances ranging from 0.24 to 2.0 $\text{ft/(ft-lb)}^{0.5}$ (0.063 to 0.52 $\text{m/(N-m)}^{0.5}$). The shaded symbols represent the maximum vibration levels measured at Location B (top of embankment) at the maximum hammer energy of 3,000 ft-lbs (4,070 N-m). As indicated previously, these levels were not significantly different than those measured at the same location when no simulated pile driving was occurring. On this basis, since no significant



SHADED SYMBOLS ARE MAXIMUM VIBRATIONS AT TOP OF EMBANKMENT WHEN ONLY GENERATOR WAS OPERATING (NO PILE DRIVING OF SIMULATED TEST PILE)

FIGURE 3

PEAK PARTICLE VELOCITY vs. SCALED DISTANCE DURING DRIVING OF SIMULATED TEST PILE
(1in/sec = 25.4mm/sec; $1\text{ft}/\sqrt{\text{ft-lb}} = 1.36\ \text{m}/\sqrt{\text{N-m}}$)

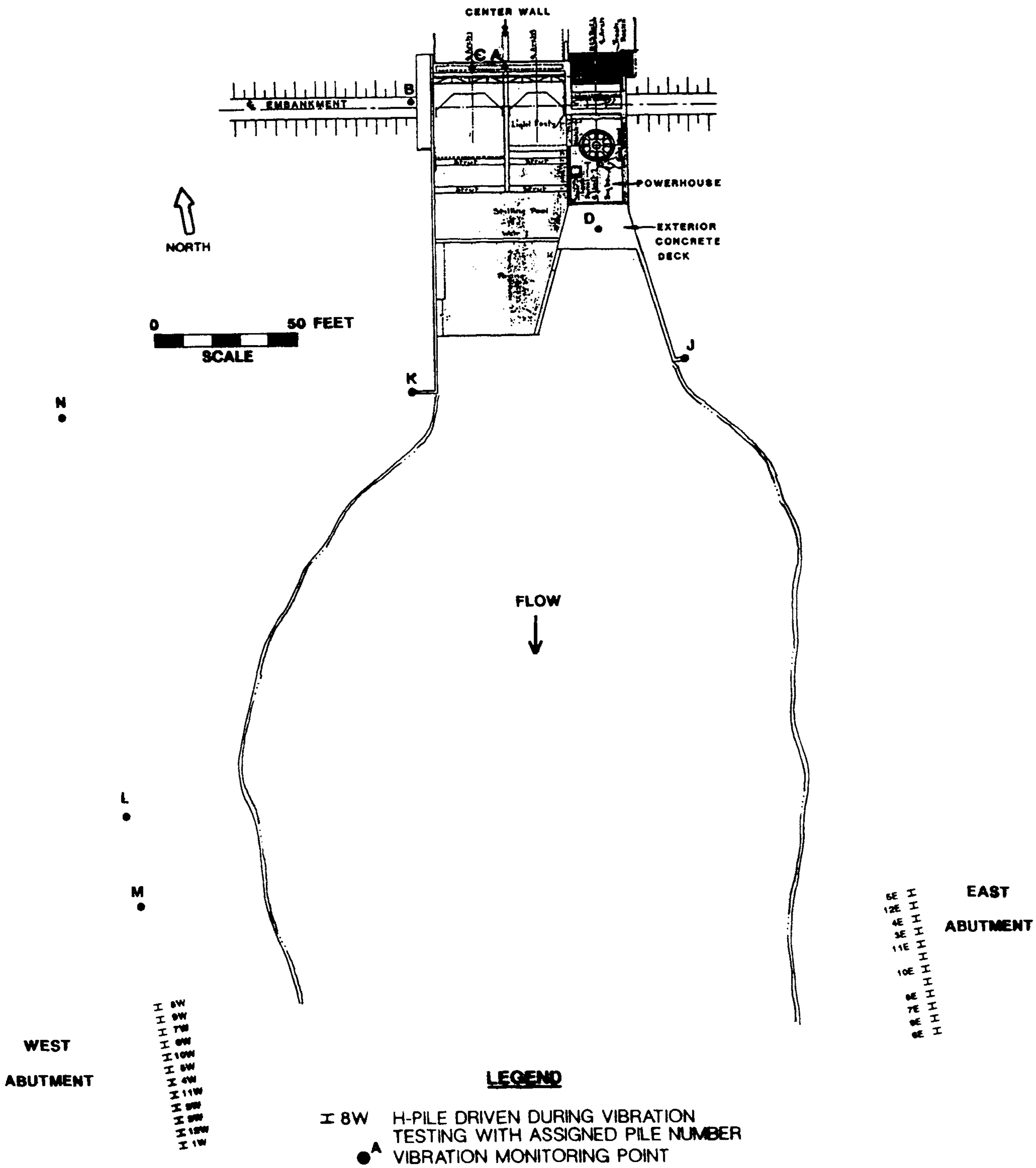


FIGURE 4

LOCATION PLAN OF SECORD DAM VIBRATION MONITORING POINTS DURING DRIVING OF PRODUCTION PILES (1m = 3.28ft.)

change in vibration levels occurs at a scaled distance of 2.0 $ft/(ft\text{-}lb)^{0.5}$ ($0.52\ m/(N\text{-}m)^{0.5}$), a permissible amount of pile driving energy for bridge construction may be predicted on the basis of a 300 foot (91.5 m) distance from the dam. An energy of about 22,000 ft-lbs (29,830 N-m) was computed.

The vibrations measured in the field were for a specific simulated pile driving operation where a pilot hole was drilled prior to installing and driving the casing. Therefore, the findings, discussed above, relate to pre-drilled holes extending into the clay hardpan before pile driving would occur. This pre-drilling sequence was implemented during installation of the production piles.

PHASE II INVESTIGATION

The Phase II investigation involved field vibration measurements to determine vibration levels on the Secord Dam from driving of the production piles for the construction of the new bridge located about 300 feet (91.5 m) downstream from the dam. The recommendation for pre-drilling through the upper materials to the hardpan layer was implemented for the bridge abutment piles during construction. However, the type of pile used in the abutments was an H-pile rather than a closed-end pipe pile which was used for the simulated pile driving evaluation. The pile hammer used for driving the piles was a Conmaco 65 with a rated energy of 19,500 ft-lb (26,440 N-m).

Vibration Measurements

Vibration measurements were taken on June 30 and July 11, 1989 by the author, during pile driving operations on the east and west abutments, respectively. The vibrations from the pile driving activities were measured by the same procedure used for the Phase I investigation.

The geophones were placed at the locations given by the alphabetically labeled symbols on the Figure 4 location plan. Monitoring locations A, C, D, J and K were situated on the dam, while the remaining monitoring points B and L through N were obtained on the ground surface at known distances from either the dam or piles. Locations A through D were at the same locations described for the Phase I investigation. Locations J and K were on top of existing retaining walls at the extreme downstream portions of the dam, on the east and west sides, respectively. The remaining monitoring points L through N were on the ground surface at the indicated locations.

Vibration Analysis and Results

Vibrations were measured on the dam for three conditions, namely: (1) ambient conditions when the generator in the powerhouse was off; (2) ambient conditions when the generator was on; and (3) during the pile driving operations. A summary of the salient measurements from these records is presented in Table 2.

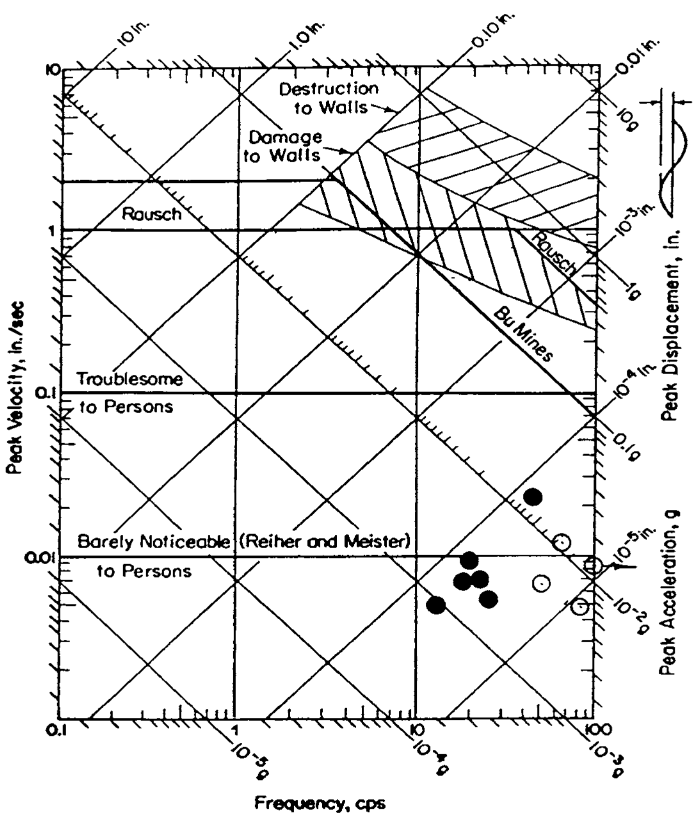
The information in Table 2 also illustrates the progressive increase in vibration level as more activities occur. The ambient condition when the generator was off represents the so-called "at rest" or no activities condition. From the Phase I study and at monitoring point D for this study, when the generator is operating (on), the vibrations increased at least one order of magnitude. Furthermore, the pile driving operations produce vibration levels equivalent to those from the operation of the generator in the dam at locations A and B and slightly lower than the "generator on" level at locations C and D. On this basis, the effects of the vibrations from pile driving activities were judged to be similar to those experienced by the dam during normal operation of the dam and from the simulated pile driving performed during the Phase I study.

TABLE 2

MAXIMUM MEASURED PEAK PARTICLE VELOCITY IN IPS
(1 ips = 25.4 mm/sec)

	SOURCE OF VIBRATION		
	AMBIENT - GENERATOR		PILE
LOCATION	OFF	ON	DRIVING
A	0.00066	0.0066*	0.0070
B	0.00051*	0.0048*	0.0050
C	-------	0.011*	0.0090
D	0.00067	0.0083	0.0054
J	0.0012	------	0.0211
K	0.00023	------	0.0069

* From Phase I Investigation



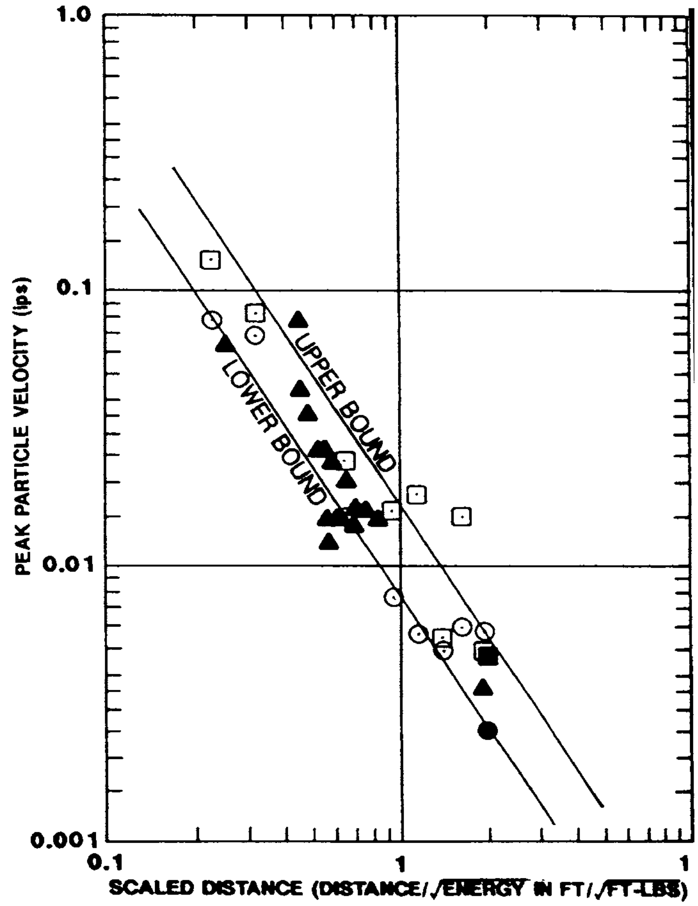
LEGEND

⊙ MAXIMUM VIBRATION - GENERATOR OPERATING
● MAXIMUM VIBRATION DURING PILE DRIVING

FIGURE 5

MAXIMUM VIBRATION LEVELS MEASURED ON OR ADJACENT TO SECORD DAM DURING PILE DRIVING ON 6/30 & 7/01/89 (1in = 25.4mm) (CHART AFTER RICHART ET AL)

The levels of the various vibrations measured on the dam are superimposed on the Figure 5 graph which illustrates the generally accepted vibration criteria of structural and subjective response. As shown by the shaded symbols, the maximum vibrations from the pile driving operations fall within the "Not Noticeable to Persons" to "Barely Noticeable to Persons" range. The open symbols, representing maximum vibrations measured from the generator operating, fall in the same general category. The vibration levels from the pile driving activities are also below the previously cited damage threshold criteria for historic and older sensitive buildings.



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⊙ VERTICLE - SIMULATED PILE DRIVING (12/86)
⊡ HORIZONTAL - SIMULATED PILE DRIVING (12/86)
▲ VERTICLE - PRODUCTION PILE DRIVING (6/89-7/89)

FIGURE 6

PEAK VELOCITY vs. SCALED DISTANCE DURING DRIVING SIMULATED TEST PILE OR PRODUCTION PILES (1in/sec = 25.4mm/sec; 1ft/$\sqrt{\text{ft-lb}}$ = 1.36 m/$\sqrt{\text{N-m}}$)

As a confirmation of the results of the so called simulated pile driving operation, vibration levels were measured at monitoring points I through N on the ground surface during the pile driving operation along the west abutment. The resulting vibration levels and computed scaled distance values are superimposed on the Figure 6 chart, along with simulated pile driving data developed from the Phase I study. These points, represented by the shaded triangle symbols, generally fall within the band-width of data gathered from the Phase I study which confirms our original hypothesis.

CONCLUSIONS

From the analysis of the field vibration tests for the Phase I investigation, it was concluded the vibrations measured at the dam were at levels which were within the "Not Noticeable to Persons" to "Troublesome to Persons" ranges based on the generally accepted criteria for modern structures in good condition. These vibration levels are also below the proposed damage threshold criteria for historic and older sensitive buildings. Even though these vibrations may be annoying to persons walking on the dam, the magnitudes were not critical to the structural integrity of the dam.

A simulated pile driving test indicated no significant change in these levels of vibrations with energy up to 3,000 ft-lbs (4,070 N-m) at a distance of 110 feet (33.5 m) from the centerline of the earth embankment. Analysis indicated that a 22,000 ft-lb (29,830 N-m) pile driving hammer, 300 feet (91.5 m) away from the centerline, would yield similar results, provided that pre-drilling through the overburden to the clay hardpan would be performed prior to driving of production piles.

From the analysis of the field vibration tests performed during driving of production piles, it was observed the vibration levels were also not critical to the structural integrity of the dam. The pile driving operations, like the simulated pile driving test, from the Phase I study, indicated no significant change in the magnitude of the vibrations.

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