SHEETPILE INSTALLATION VIBRATION STUDY

Kenneth A. Pidgeon, P.E.,[1] Sanjeev A. Joshi, P.E.,[2] and Kevin DiRocco[3]

Abstract

This paper presents a case history on mitigating vibration problems associated with the installation of steel sheetpiles. The project includes installation of steel sheetpiles for a utility trench within 40 feet (12.2 meters)of a very sensitive manufacturing facility. Numerous production line quality control instruments and manufacturing processes within the manufacturing facility are extremely sensitive to vibrations. To minimize the impact to the owner, we specified that the contractor perform a vibration study using different types of pile hammers. The results and conclusions of the vibration study are presented in this paper.

Introduction

The site is located adjacent to a large manufacturing facility in Boston, Massachusetts. The manufacturing facility is extremely sensitive to vibrations. The products manufactured at the facility require strict tolerances and are subjected to rigorous quality control checks. A new utility adjacent to the manufacturing facility required an 800-foot(244 meter)-long trench (Fig. 1) varying in depth from about 14 to 17 feet (4.3 to 5.2 meters)deep. Sheetpiles were required to control the shallow ground water and to minimize the area required for excavation.

Subsurface Conditions

The soils consist of the following layers, starting at the ground surface:

Fill: About 18 to 21 feet (5.5 to 6.4 meters) of fill containing sand, silt, clay, gravel, concrete blocks, brick fragments, coal, ash, and other debris. Several samples obtained at depths ranging from 6 to 16 feet (1.8 to 4.9 meters) consisted mainly of gravel and concrete and brick fragments.

Organic Deposit: The thickness of the organic deposit ranged from 10 to 13 feet (3.0 to 4.0 meters). The deposit generally consists of an organic clayey silt or sandy silt with occasional peat fibers and wood fragments.

Silty Clay: The silty clay layer was encountered in the borings at a depth of about 30 feet (9.1 meters). The thickness of the layer ranged from 22 to 30 feet (6.7 to 9.1 meters).

[1]Project Manager, GEI Consultants, Inc., Winchester, Massachusetts
[2]Project Engineer, GEI Consultants, Inc., Winchester, Massachusetts
[3]Project Engineer, GEI Consultants, Inc., Winchester, Massachusetts

Glacial Till: Glacial till was encountered in the borings at depths ranging from 52 to 60 feet (15.8 to 18.3 meters). The till generally consisted of a silty sand with gravel with low to medium plasticity fines.

Bedrock: Bedrock, consisting of Cambridge Argillite, was encountered in the borings at a depth of about 75 feet (22.9 meters).

Ground Water: Due to the proximity of the site to Boston Harbor, the depth to ground water varies almost directly with the tide level (about 5 to 15 feet [1.5 to 4.6 meters] below ground surface).

Existing Manufacturing Building

The existing manufacturing building is a single-story structure with a partial basement. The first-floor elevation is about 4.5 feet (1.4 meters) above ground surface. The basement level is about 3.5 feet (1.1 meters) below ground surface.

The building is mostly supported on pressure-injected footings (PIFs) bearing in the glacial till. In the area where the vibration study was performed, the PIFs are spaced in groups at 20 feet (6.1 meters) on center. The groups consist of either one or two PIFs. The groups containing two PIFs support the first floor slab and columns for the roof structure. The single PIFs support the first floor only. The typical design floor load for the first floor is 400 psf (8.35 N/m^2).

Several sections of the building were founded directly on abandoned foundations remaining from previous structures. These abandoned foundations are supported by closely spaced timber piles driven into clay.

Contract Requirements

The specifications required that the contractor not create any vibrations that exceed background levels. If necessary, the contractor was required to use the hydraulic non-impact Stillworker™ hammer.

The specifications also required that the contractor perform a vibration study to allow the engineer to evaluate different pile hammers including:

- The hydraulic non-impact Stillworker™,
- A vibratory hammer, and
- An impact hammer.

The objectives of the study were to 1) evaluate the performance of the different hammers and 2) evaluate whether the vibrations generated by the vibratory and impact hammer would impact the owner enough to warrant the use of the Stillworker™.

Description of Vibration Study

Five pile driving hammers (including one impact diesel, two impact hydraulic, and two vibratory hydraulic hammers) were used to drive pairs of PZ-27 sheetpiles at four locations. The sheetpile installation locations and vibration measurement locations are shown in Fig. 1. The sheetpiles were driven to a maximum depth of 40 feet (12.2 meters) below the ground surface. Each sheetpile location was pre-excavated prior to installation.

The hammer types and energies are given below. The hydraulic Stillworker™ was not included in this phase of the study. The contractor's proposal to use other locally available hammers was accepted under the condition that the Stillworker™ be included in the test if the other hammers proved unacceptable.

Hammer	Type	Energy Supply	Rated Maximum Energy or Dynamic Force
MKT DA-35B	Impact	Diesel Combustion	21,000 foot-pounds (28,472 joules)
Dawson HPH-1200	Impact	Hydraulic Pump	8,680 foot-pounds (11,769 joules)
Dawson HPH-2400	Impact	Hydraulic Pump	17,360 foot-pounds (23,537 joules)
H&M H-75B	Vibratory	Hydraulic Pump	32 tons (285 kilo newtons)
Vulcan V-2300	Vibratory	Hydraulic Pump	83.6 tons (744 kilo newtons)

The manufacturing facility was shut down for maintenance on February 18 and 19, 1995, when the vibration study was started. An additional hammer was tested on February 22, 1995, when the facility was in operation.

Vibrations were monitored at the locations M-1 through M-12 shown in Fig. 1. Measurements were taken using four Geosonics SSU 2000DK seismographs. These seismographs simultaneously record vibration components in three orthogonal directions. At each monitoring location, the geophone was placed on the ground surface or the floor and aligned so that the longitudinal (L) axis for vibration recording was directed toward the west wall of the building. Using amplifiers, the seismograph can measure a minimum peak particle velocity (PPV) of 0.001 inch per second (0.03 mm/s).

A continuous, 15-second record was obtained after the peak particle velocity exceeded the trigger value (typically 0.002 inch per second [0.05 mm/s]). On February 22, 1995, when manufacturing activities caused background vibration up to 0.03 inch per second (0.76 mm/s)(PPV), triggering was manually operated and coordinated with the start of the sheetpile installation. Several 15-second records were obtained at three or four monitoring locations for each pile driving location and hammer.

For each 15-second record, peak particle velocities, the associated vibration frequencies, and time history of the vibration record were automatically printed out on paper and saved on a computer diskette.

Background Vibration Levels

Background vibrations vary widely throughout the manufacturing facility. Some of the large assembly machines produced vibrations up to 0.035 inch/second (0.89 mm/s). The background vibrations in other manufacturing areas were as low as 0.010 inch/second (0.25 mm/s). Background levels in some of the quality control instrumentation areas were less than 0.010 inch/second (0.25 mm/s). These areas were particularly sensitive to vibrations above background levels.

Results of Vibration Study

Tables 1 through 5 summarize the peak vibration levels measured for the five different pile driving hammers. Peak vibrations recorded inside the manufacturing building for the five different hammers are given below.

Pile Hammer	Peak Particle Velocity Measured Inside Building					
	Maximum		Minimum		Average	
	(in./sec.)	(mm/s)	(in./sec.)	(mm/s)	(in./sec.)	(mm/s)
DA-35B Impact Diesel	0.032	0.81	0.016	0.41	0.022	0.56
HPH-1200 Impact Hydraulic	0.026	0.66	0.006	0.15	0.014	0.36
HPH-2400 Impact Hydraulic	0.050	1.27	0.011	0.28	0.030	0.76
H-75B Vibratory Hydraulic	0.029	0.74	0.005	0.13	0.011	0.28
V-2300 Vibratory Hydraulic	0.045	1.14	0.007	0.18	0.025	0.64

The HPH-2400 and the MKT DA-35B were the only hammers capable of efficiently driving the sheetpiles into the clay.

Conclusions

Based on the results of the vibration study, we made the following recommendations to our client:

1. Pretrench along the sheetpile alignment to remove any potential obstructions. The site contained numerous obstructions including abandoned concrete foundations and granite block seawalls that

required removal. With most of the obstructions removed, we expected smoother installation with lower vibrations.

2. Sheetpile installation should be performed as described below.
   - Initially, the sheetpiles should be installed using the H-75B vibratory hammer. This is a relatively small hammer that was generally capable of driving the sheetpiles through the fill and organic layers to the top of the silty clay.
   - After obtaining refusal with the H-75B, the contractor should use the H-1200 hydraulic impact hammer set at half stroke.

3. Additional vibration monitoring should be performed during installation of the sheetpiles for the trench excavation.

TABLE 1 - VIBRATIONS DUE TO DA-35B IMPACT DIESEL HAMMER

Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3]	Peak Particle Velocity (inch/second)[3]	Remarks
2/18/95	H-1	95	M-6	15	0.070	M-6 located ouside building.
2/18/95	H-1	120	M-5	15	0.025	
2/18/95	H-1	120	M-5	35	0.016	
2/18/95	H-1	150	M-2	3	0.029	
2/18/95	H-1	150	M-2	18	0.022	
2/18/95	H-1	150	M-2	36	0.019	
2/18/95	H-1	170	M-3	15	0.020	
2/18/95	H-1	170	M-3	32	0.016	
2/18/95	H-1	170	M-3	39	0.019	
2/18/95	H-3	80	M-1	25	0.030	
2/18/95	H-3	95	M-2	9	0.018	
2/18/95	H-3	115	M-3	9	0.032	
2/18/95	H-3	115	M-3	16	0.023	
2/18/95	H-3	115	M-3	23	0.016	

General Notes:

1. Refer to Fig. 1 for sheetpile and monitoring locations.
2. Maximum hammer stroke used.
3. 1 foot = 0.3048 meter, and 1 inch/second = 25.4 mm/second.

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TABLE 2 - VIBRATIONS DUE TO HPH-1200 IMPACT HYDRAULIC HAMMER
Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[2)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[2)]	Peak Particle Velocity (inch/second)[2)]	Remarks
2/19/95	H-4	40	M-12	12	0.040	M-12 located outside building.
2/19/95	H-4	40	M-12	15	0.110	M-12 located outside building.
2/19/95	H-4	40	M-12	16	0.050	Hammer at 50% stroke. M-12 located outside building.
2/19/95	H-4	50	M-9	12	0.016	Hammer at 50% stroke
2/19/95	H-4	50	M-9	14	0.009	Hammer at minimum stroke
2/19/95	H-4	50	M-9	15	0.009	Hammer at 50% stroke
2/19/95	H-4	50	M-9	16	0.018	Hammer at 50% stroke
2/19/95	H-4	50	M-9	22	0.009	Hammer at minimum stroke
2/19/95	H-4	50	M-9	23	0.017	Hammer at minimum stroke
2/19/95	H-4	80	M-10	8	0.013	Hammer at 50% stroke
2/19/95	H-4	80	M-10	12	0.011	Hammer at 50% stroke
2/19/95	H-4	80	M-10	13	0.012	Hammer at minimum stroke
2/19/95	H-4	80	M-10	16	0.015	Hammer at 50% stroke
2/19/95	H-4	80	M-10	21	0.009	Hammer at minimum stroke
2/19/95	H-4	80	M-10	22	0.013	Hammer at 50% stroke
2/19/95	H-4	110	M-11	8	0.012	Hammer at 50% stroke

TABLE 2 - VIBRATIONS DUE TO HPH-1200 IMPACT HYDRAULIC HAMMER
Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[2)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[2)]	Peak Particle Velocity (inch/second)[2)]	Remarks
2/19/95	H-4	110	M-11	11	0.013	Hammer at 50% stroke
2/19/95	H-4	110	M-11	12	0.011	Hammer at 50% stroke
2/19/95	H-4	110	M-11	12	0.012	Hammer at minimum stroke
2/19/95	H-4	110	M-11	16	0.017	Hammer at 50% stroke
2/19/95	H-4	110	M-11	21	0.012	Hammer at minimum stroke
2/19/95	H-4	110	M-11	23	0.014	Hammer at 50% stroke

General Notes:

1. Refer to Fig. 1 for sheetpile and monitoring locations.
2. 1 foot = 0.3048 meter, and 1 inch/second = 25.4 mm/second.

TABLE 3 - VIBRATIONS DUE TO HPH-2400 IMPACT HYDRAULIC HAMMER
Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3)]	Peak Particle Velocity (inch/second)[3)]	Remarks
2/22/95	H-2	85	M-7	4	0.050	
2/22/95	H-2	85	M-7	18	0.040	
2/22/95	H-2	90	M-5	4	0.025	
2/22/95	H-2	90	M-5	16	0.011	
2/22/95	H-2	90	M-5	16	0.035	
2/22/95	H-2	90	M-5	18	0.027	
2/22/95	H-2	90	M-5	26	0.033	
2/22/95	H-2	90	M-5	29	0.029	
2/22/95	H-2	90	M-5	31	0.021	
2/22/95	H-2	90	M-5	31	0.032	
2/22/95	H-2	90	M-5	32	0.030	
2/22/95	H-2	90	M-5	32	0.033	
2/22/95	H-2	90	M-5	35	0.028	
2/22/95	H-2	90	M-5	36	0.013	
2/22/95	H-2	110	M-8	4	0.035	
2/22/95	H-2	110	M-8	21	0.027	
2/22/95	H-2	110	M-8	26	0.030	
2/22/95	H-2	110	M-8	31	0.032	

TABLE 3 - VIBRATIONS DUE TO HPH-2400 IMPACT HYDRAULIC HAMMER
Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3)]	Peak Particle Velocity (inch/second)[3)]	Remarks
2/22/95	H-2	110	M-8	33	0.037	
2/22/95	H-2	110	M-8	33	0.024	
2/22/95	H-2	120	M-2	3	0.035	
2/22/95	H-2	120	M-2	20	0.026	

General Notes:

1. Refer to Fig. 1 for sheetpile and monitoring locations.
2. Minimum hammer stroke used during vibration measurement.
3. 1 foot = 0.3048 meter, and 1 inch/second = 25.4 mm/second.

TABLE 4 - VIBRATIONS DUE TO H-75B VIBRATORY HAMMER

Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3)]	Peak Particle Velocity (inch/second)[3)]	Remarks
2/18/95	H-3	80	M-1	4	0.013	
2/18/95	H-3	80	M-1	23	0.012	
2/18/95	H-3	95	M-2	13	0.011	
2/18/95	H-3	95	M-2	23	0.021	
2/18/95	H-3	95	M-2	25	0.029	
2/18/95	H-3	115	M-3	4	0.009	
2/18/95	H-3	135	M-4	5	0.006	
2/18/95	H-3	135	M-4	23	0.006	
2/19/95	H-4	40	M-12	6	0.060	M-12 located outside building.
2/19/95	H-4	40	M-12	10	0.050	M-12 located outside building.
2/19/95	H-4	50	M-9	15	0.009	
2/19/95	H-4	80	M-10	4	0.008	
2/19/95	H-4	80	M-10	14	0.008	
2/19/95	H-4	110	M-11	8	0.005	
2/19/95	H-4	110	M-11	14	0.008	

General Notes:

1. Refer to Fig. 1 for sheetpile and monitoring locations.
2. Maximum hammer stroke used during vibration measurements.
3. 1 foot = 0.3048 meter, and 1 inch/second = 25.4 mm/second.

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TABLE 5 - VIBRATIONS DUE TO V-2300 VIBRATORY HAMMER
Sheetpile Installation Vibration Study

Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3)]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3)]	Peak Particle Velocity (inch/second)[3)]	Remarks
2/18/95	H-1	95	M-6	34	0.060	M-6 located outside building.
2/18/95	H-1	120	M-5	9	0.007	
2/18/95	H-1	120	M-5	28	0.016	
2/18/95	H-1	120	M-5	34	0.041	
2/18/95	H-1	120	M-5	35	0.045	
2/18/95	H-1	150	M-2	8	0.011	
2/18/95	H-1	150	M-2	27	0.008	
2/18/95	H-1	150	M-2	34	0.032	
2/18/95	H-1	170	M-3	8	0.029	
2/18/95	H-1	170	M-3	27	0.011	
2/18/95	H-1	170	M-3	33	0.029	
2/18/95	H-3	40	M-6	(a)	0.290	During extraction. M-6 located outside building.
2/18/95	H-3	40	M-6	23	0.200	M-6 located outside building.
2/18/95	H-3	65	M-5	(a)	0.035	During extraction
2/18/95	H-3	65	M-5	23	0.034	
2/18/95	H-3	80	M-1	(a)	0.032	During extraction
2/18/95	H-3	80	M-1	23	0.038	
2/18/95	H-3	95	M-2	(a)	0.020	During extraction

TABLE 5 - VIBRATIONS DUE TO V-2300 VIBRATORY HAMMER
Sheetpile Installation Vibration Study

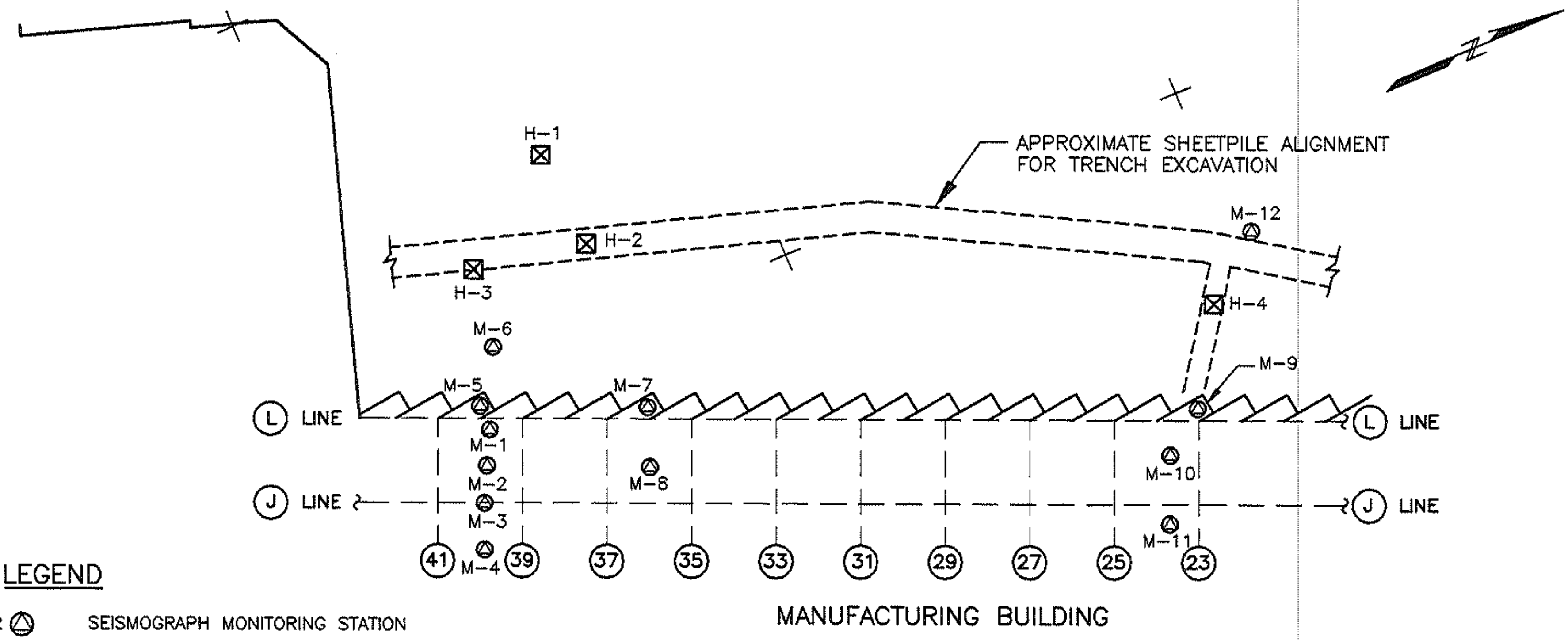
Date	Sheeting and Hammer Location	Distance From Monitoring Station to Sheeting (feet)[3]	Monitoring Station No.	Approximate Sheeting Depth (feet)[3]	Peak Particle Velocity (inch/second)[3]	Remarks
2/19/95	H-4	40	M-12	(a)	0.100	During extraction. M-12 located outside building.
2/19/95	H-4	50	M-9	(a)	0.009	During extraction

Footnotes:

(a) Depth not measured during pile extraction.

General Notes:

1. Refer to Fig. 1 for sheetpile and monitoring locations.
2. Maximum dynamic force used during vibration measurement.
3. 1 foot = 0.3048 meter, and 1 inch/second = 25.4 mm/second.



LEGEND

M-2 SEISMOGRAPH MONITORING STATION

H-2 HAMMER AND PILE DRIVING LOCATION

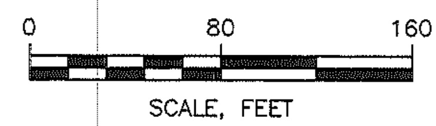
41 / L COLUMN LINE INSIDE BUILDING

SHEETPILE VIBRATION STUDY LOCATION PLAN

Fig. 1

METRIC SCALE

1 cm = 9.6 meters



NOTE:

HAMMER AND MONITORING STATION LOCATIONS:

DATE	SEISMOGRAPH MONITORING STATION LOCATIONS	HAMMER AND SHEET PILE LOCATIONS	HAMMER TYPES
2/18/95	M-1 THROUGH M-6	H-1 AND H-3	H-75B VIBRATORY HPH-1200 HYDRAULIC IMPACT DA-35B DIESEL IMPACT AND V-2300 VIBRATORY
2/19/95	M-9 THROUGH M-12	H-4	H-75B VIBRATORY AND HPH-1200 HYDRAULIC IMPACT
2/22/95	M-2, M-5, M-7 AND M-8	H-2	HPH-2400 HYDRAULIC IMPACT

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94321-50 6/22/95 BEM/OLJ/PTC