DISPLACEMENT AND PORE PRESSURE MONITORING DURING INSTALLATION OF DRILLED DISPLACEMENT PILES

Lisa M. Splitter, P.E., Treadwell & Rollo, Inc., Oakland, California, USA
Lori A. Simpson, P.E., G.E., Treadwell & Rollo, Inc., Oakland, California, USA

Drilled displacement piles were constructed as the foundation for a proposed 10-story building in San Francisco, California. At the study location, the stratigraphy consists of 14 to 21 feet of fill and 13 to 23 feet of weak, compressible clay ("Bay Mud"), underlain by dense sand, stiff clay, and bedrock. A sensitive critical public utility is located within approximately 20 feet of the constructed piles along one side of the building. The utility pipeline is entirely within the Bay Mud where it is adjacent to the project site. The San Francisco Public Utilities Commission (SFPUC) developed limits on the allowable total and differential movement of the utility pipeline. As requested by the SFPUC, inclinometers and piezometers were installed to monitor the soil movement and pore pressure increases in the Bay Mud caused by the installation of drilled displacement piles. Action levels were set such that if displacement and/or pore pressures reached an action level, the installation methodology would be reevaluated and additional measures to reduce these effects would be implemented.

This paper will present the sequence of pile installation near the pipeline and monitoring points, and the data collected from inclinometers and piezometers at variable depths and distances from the piles. The data will highlight the build-up and dissipation of pore pressures over time and the displacement of Bay Mud caused by the pile installation. The conclusions of the study are useful in determining sequencing, spacing, predrilling, and other measures that can be implemented to decrease the displacement potential and pore pressure build-up in soft clays.

INTRODUCTION

The foundation design for a proposed 10-story building in San Francisco, California included the construction of drilled displacement "Omega" piles. A large diameter combined sanitary sewer and storm drain pipeline is located outside of the building footprint 21-1/2 feet from the closest pile, as shown on Figure 1 below. At the study location, the stratigraphy consists of heterogeneous fill and weak, compressible clay ("Bay Mud"), underlain by dense sand, stiff clay, and bedrock.

The pipeline is entirely embedded within the Bay Mud where it is adjacent to the project site. Before the installation of piles in close proximity to the pipeline could proceed, a monitoring program had to be developed and approved by the San Francisco Public Utilities Commission (SFPUC). The SFPUC was concerned that displacements during the installation of the piles would cause excessive movement of the pipeline and/or that excess pore pressures would result in uplift forces and movement of the pipeline. The SFPUC set guidelines for maximum pipe displacement and requested that inclinometers and piezometers be installed to measure soil movement and pore pressures. Inclinometers and piezometers were installed, and monitored during installation of the closest piles.

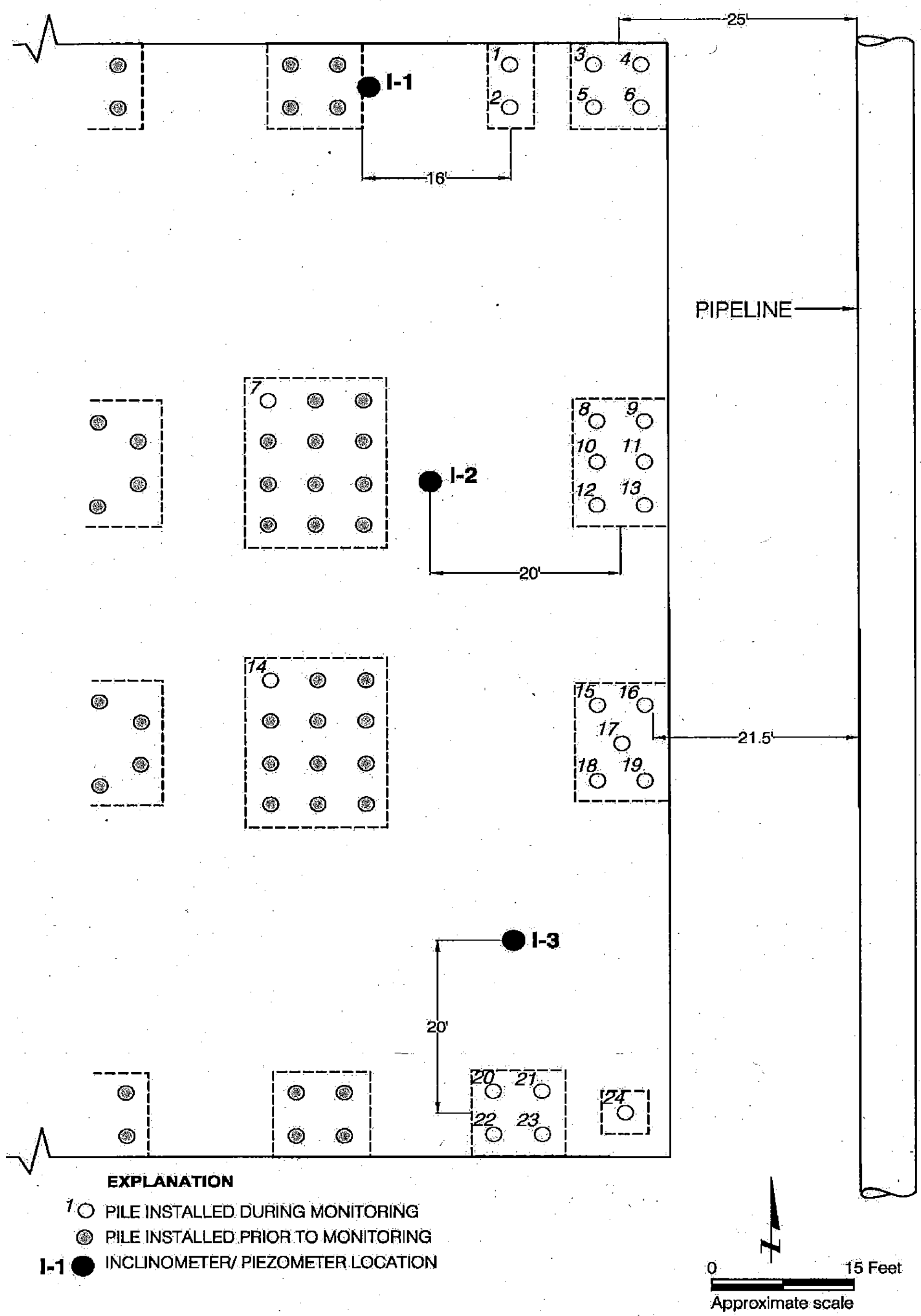

Figure 1. Site Plan.

SUBSURFACE CONDITIONS

The site is blanketed by 14 to 21 feet of fill consisting of gravel, sand, silt, and clay mixtures and is very loose to very dense and soft to hard. The fill is underlain by 13 to 23 Fee of week compressible clay ("Bay Mud")

The Bay Mud is very soft to soft and the undrained shear strength values range from approximately 350 to 600 pounds per square foot (psf). Dense sand and stiff clay underlie the Bay Mud, with bedrock varying from approximately 67 to 94 feet below the ground surface. The conditions nearest the pipeline are summarized on Figure 2.

The pipeline is approximately 21-1/2 feet from the nearest line of piles. The top of the pipe is approximately 15 feet below the ground surface and is embedded entirely in Bay Mud. The location of the pipeline relative to the nearest pile is also shown in Figure 2.

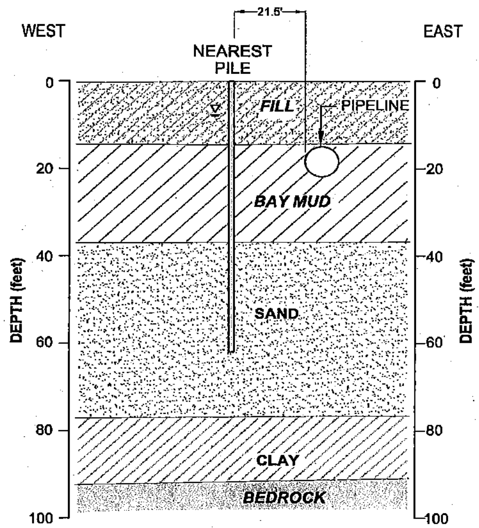

Figure 2. Cross-section.

PILE INSTALLATION

Drilled displacement Omega piles were installed to support the proposed building. Omega piles are a drilled foundation type that is constructed using an auger with a displacement tool connected to a solid stem, as shown in Figure 3. The displacement tool does not allow spoils to come to the ground surface. At this site, low vibrations and little spoils were preferred by the project owner. After the auger is drilled to the final depth, concrete is pumped under pressure to dislodge a sacrificial tip and the auger is removed from the hole as concrete is being poured. After the auger is removed, a center bar and rebar cage is lowered into the hole. The proposed building will be supported on 287, 62-foot long Omega piles that are 18 inches in diameter. The piles were installed using a Bauer BG-40 rig with 88,000 lbs of available crowd and maximum torque of 295,000 ft. lbs. The installation platform is shown on Figure 3. The piles were designed to gain support through friction and toe resistance in dense sand that is present below the Bay Mud. 263 piles were installed prior to beginning the monitoring program. Based on previous experience gained on a nearby site located approximately the same distance from the pipeline, the monitoring program was established before the installation of the piles within 50 feet of the pipeline. It is unknown if soil movement at the pipeline occurred from the installation of the first 263 piles. The 24 piles installed during the monitoring program are indicated in Figure 1.

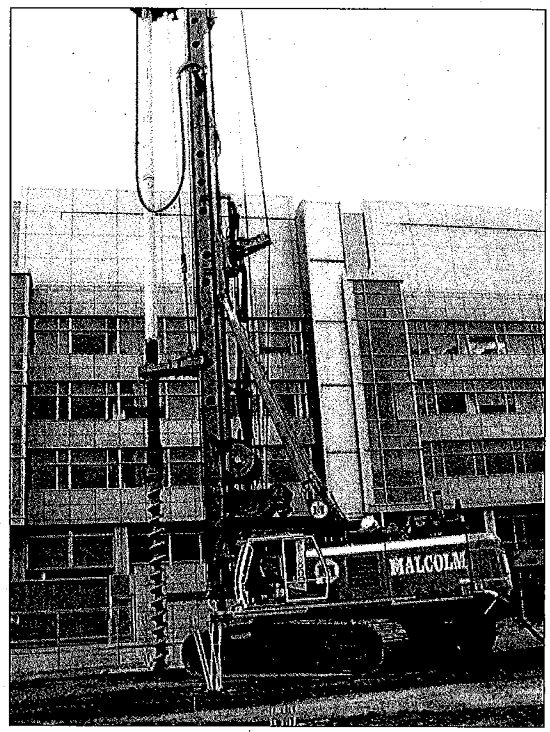

Figure 3. Bauer BG-40 Pile Rig

Before monitoring began, it was decided to perform predrilling prior to the installation of piles within 50 feet of the pipeline, in order to reduce the potential for displacement in the Bay Mud at the depth of the pipeline. The predrilling program consisted of drilling a 24-inch diameter solid flight auger to a depth of approximately five feet below the bottom elevation of the pipeline. The installation of the piles began within approximately 2 hours of predrilling; however, the predrill holes did not stay open within the Bay Mud.

MONITORING PROGRAM

Three inclinometers and three piezometers were installed at the locations shown on Figure 1. The project general contractor was not allowed to perform any work outside of the building footprint nor was it allowed access to the pipeline for surveying. Because work could only be performed within the building footprint, the inclinometers and piezometers were constructed at a distance from the pile caps similar to the distance between the pile caps and the pipeline, given the constraints of the other pile caps nearby.

The piezometers were extended to three different depths to capture the change in pore water pressure at different elevations. The piezometer elevations corresponded to the midpoint, bottom, and five feet below the bottom of the pipeline.

The threshold for the maximum inclinometer movement was developed using the SFPUC allowable deflection criteria for pipeline. The SFPUC specified that the pipeline movement be limited to 1-1/2 inches at any point and not more than 1/2 inch of differential movement in 30 feet. Because the pipeline could not be surveyed, it was assumed that the maximum soil movement measured in the inclinometers was equivalent to pipeline movement.

In addition, it was assumed that there would be no movement of the pipeline 30 feet north and south of the location of the closest pile activity, a conservative assumption when considering the allowable differential movement. Therefore, in order to meet the differential movementt criteria, the maximum movement could not exceed 1/2 inch. Consequently, the threshold value for lateral soil movement was set at 1/2 inch, with the action level at 1/4 inch.

The action level for maximum total pore water pressure was developed such that the pressure would be less than one half of the overburden load on the pipeline. At this action level, there would be a factor of safety of 2 against hydrostatic uplift of the pipe.

Measurements were obtained once or twice during each day of pile installation. The inclinometer and piezometer measurements taken were compared with action levels set prior to beginning the program. If the maximum values were equal to or greater than the action levels, the pile operation would stop and the installation method would be reevaluated to incorporate additional mitigation measures.

MONITORING RESULTS

Inclinometers I-1, I-2, and I-3 were monitored during the installation of the 22 piles nearest the pipeline plus 2 additional remaining piles further away. The inclinometer data collected are presented on Figures 4, 5, and 6.

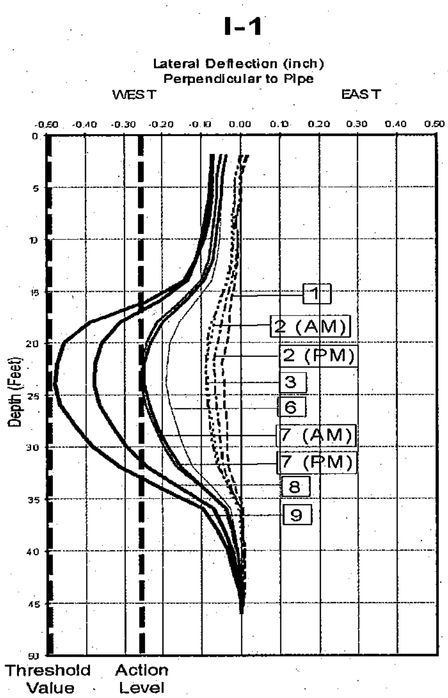

Figure 4a. Inclinometer I -1 West-East Direction

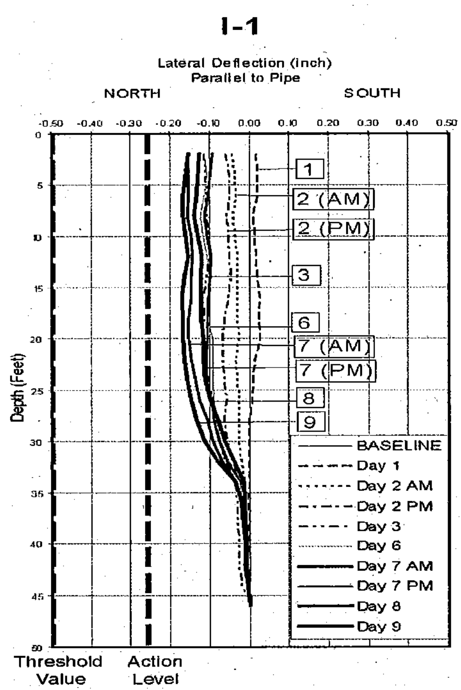

Figure 4b. Inclinometer I -1 North-South Direction

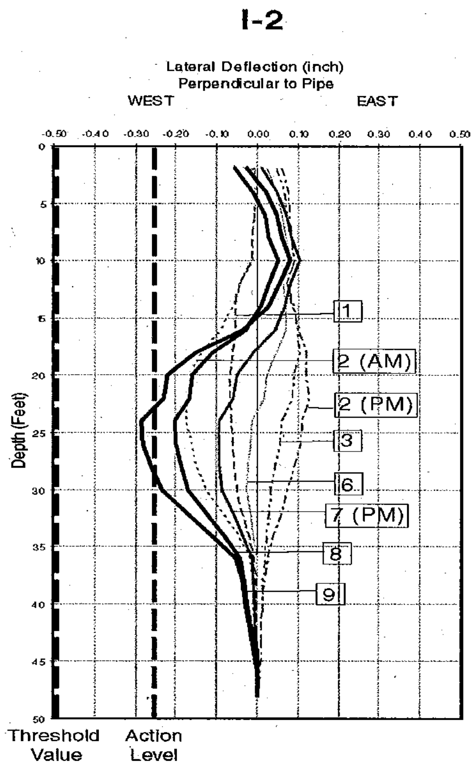

Figure 5s, Inclinometer 1 – 2 West-East Direction

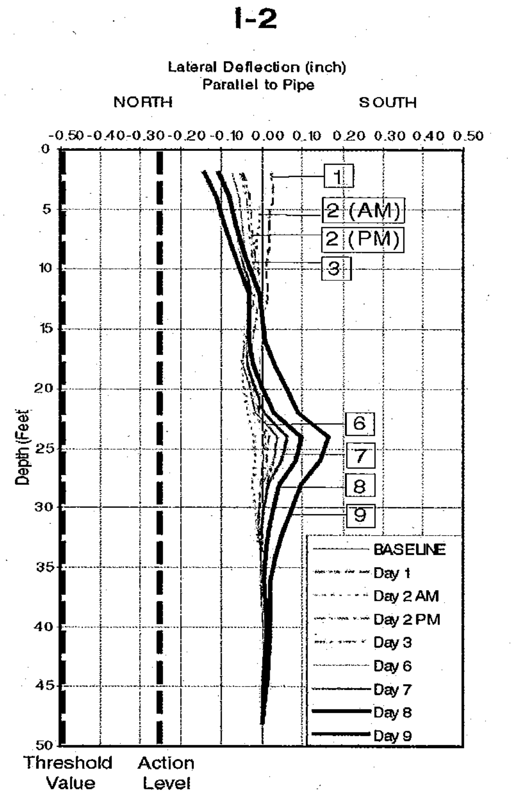

Figure 5b. Inclinometer 1 – 2 North-South Direction

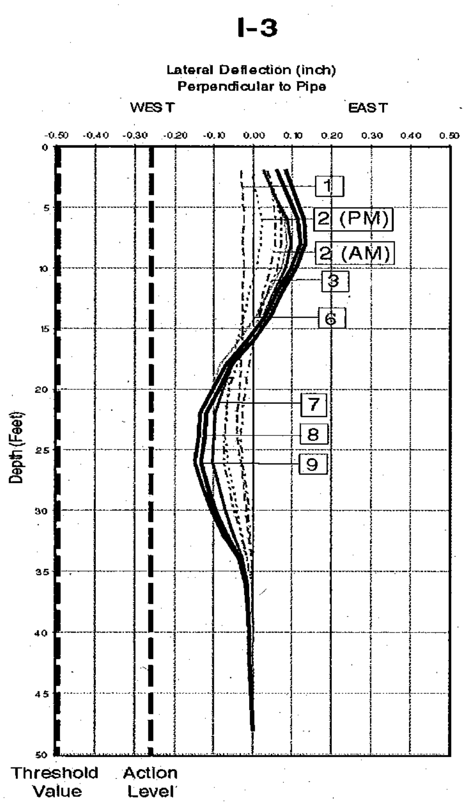

Figure 6a. Inclinometer I - 3 West-East Direction.

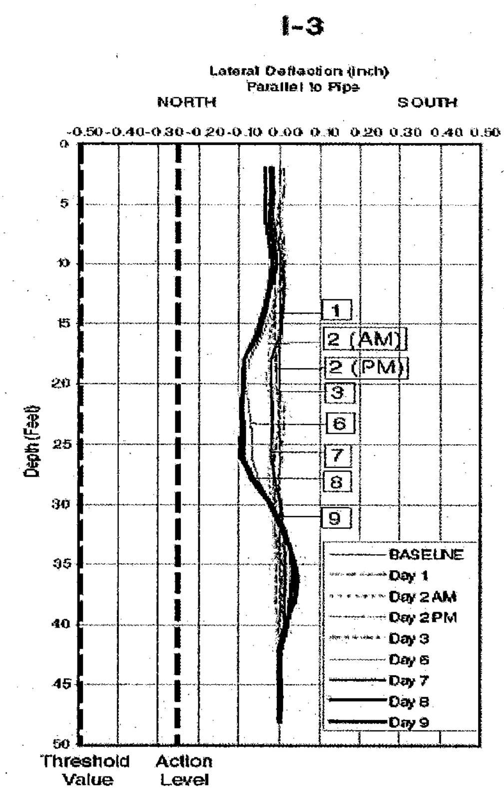

Figure 6b. Inclinometer I - 3 West-East Direction

On day 7, when the action displacement value of 1/4 inch was measured in I-1, the predrilling was deepened by approximately 10 feet for the remaining 6 piles and each location was predrilled twice; however, these actions did not appear to reduce the displacement. Upon completion of pile installation, the threshold value had not been exceeded.

Note that inclinometer I-1 is only 16 feet away from the closest piles; therefore, the soil displacement at the pipeline 21 ½ feet away should be less than that measured in I-1. Piezometers were measured continuously during installation of the last 24 piles. The measured pore pressures and the action level at each depth are shown below in Figure 7. While pore pressures spiked during pile installation, they decreased rapidly and the action level was never exceeded.

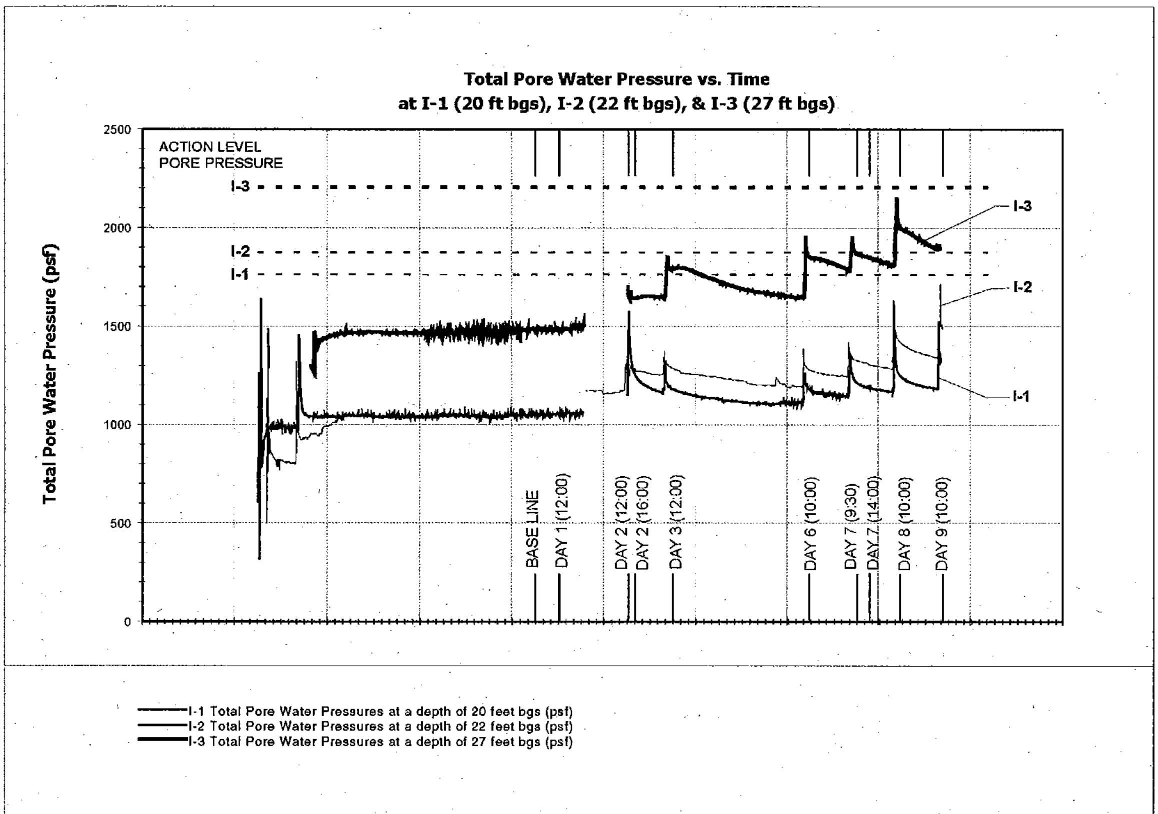

Figure 7. Total Pore Water Pressure vs. Time.

Table 1 summarizes the pile installation sequence on each day following the baseline reading and presents the maximum cumulative lateral movement measured. The baseline measurement was taken on Day 0; piles were not installed until the second day following the baseline reading.

Table 1. Maximum Cumulative Soil Movement

Day[1]	Pile Number	Time		Maximum Cumulative Movement and Movement Direction (inch)		
		Begin Drilling	End Concrete Placement	I-1	I-2	I-3
2	4	10:40	11:05			
	13	11:11	11:33			
	16	11:38	11:59			
	24	12:11	12:56			
	7	13:01	13:21			
	14	13:25	13:55	0.09 (west)	0.18 (west)	0.07 (west)
3	6	7:41	8:14			
	11	8:20	8:40			
	19	8:44	9:01			
	23	9:06	9:41	0.09 (west)	0.10 (east)	0.08 (west)
6	3	8:25	8:43			
	9	8:46	9:04			
	17	9:09	9:27			
	21	9:31	9:48	0.19 (west)	0.08 (east)	0.13 (west)
7	5	8:07	8:23			
	8	8:27	9:02			
	15	9:08	9:24			
	22	9:29	10:12	0.25 (west)	0.10 (west)	0.10 (west)
8	1	7:44	8:03			
	10	8:08	8:42			
	18	8:45	9:04			
	20	9:08	9:42	0.38 (west)	0.20 (west)	0.15 (west)
9	12	7:23	7:40			
	2	8:10	8:27	0.48 (west)	0.28 (west)	0.12 (west)

[1] Days following baseline reading (Day 0).

CONCLUSIONS

Installation of Omega piles caused displacement and increased pore pressures of soft clay 16 to 20 feet away from the pile caps. The majority of the soil movement generally occurred in the soft clay and not in the fill or sand. Pore pressure were only measured in the soft clay.

Inclinometer I-1 was "perpendicular" to line of the remaining 24 piles while I-2 and I-3 were influenced by pile caps installed to the north and to the south. The evidence of the caps of influence is shown on the inclinometer plots where the soil movement occurs in the positive and negative directions. Therefore, during pile installation, the Bay Mud is likely "pushed" back and forth depending on where piles are being installed. This data further supports the theory that installing piles in one continuous direction can have a larger impact on nearby improvements.

Based on the results of the monitoring program, we conclude that a 6-pile cap of predrilled, drilled displacement piles can cause approximately 1/4 to 1/2 inch of lateral displacement in soft clay approximately 20 feet away from the center of the cap. A single pile can cause about 1/10 inch of displacement. On Day 2 and Day 7, measurements were taken during pile installation an shortly after installation. Based on the two measurements it appears that some soil relaxation does occur with time, but the length of time it takes and magnitude of the relaxation is unknown based on this program.

The installation method causes significant pore pressure increases. The pile installation caused spikes in pore pressures, but each spike was followed by relatively rapid decrease. However, the rapid decreases in pore pressures did not reach the original static levels. Even over a weekend with no pile installation, pore pressures did not decrease to original static levels. Over several days of installation there is a net increase in pore pressure.

Additional predrilling had little effect on reducing the lateral movement and pore pressure increases. Since the pile installation was completed as the soil movement neared the threshold values, changes to the installation method were not necessary. If needed, considerations would have been given to drilling open holes between the pile locations and the pipeline to "absorb" some of the deflection, installing gravel drains surrounding the pile caps to relieve excess pore pressures and/or stopping work until the pore pressures decreased and the soil relaxed.

It would be useful for future studies to evaluate the displacement and pore pressure increases caused by drilled displacement piles without predrilling, as it is not typical to predrill this pile type. Future studies could also compare the differences in pore pressure increases and displacement between displacement, and non-displacement auger cast piles.

ACKNOWLEDGEMENTS

The authors would like to thank Peter Faust with Malcolm Drilling Company, Inc. for his peer review of this paper.