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Memorandum

Date: August 20, 2018

To: Christos Tsiamis, EPA Project Manager

Copies to: Gowanus Canal RD Group

From: Howard Cumberland, Project Coordinator

Subject: TB4 Pilot Study Observations during Bulkhead Support Installation

INTRODUCTION

As part of the 4th Street Turning Basin (TB4) Pilot Study, information is being gathered that should be considered during subsequent phases of the design and implementation of the Gowanus Canal (Canal) remedy. Attached to this memorandum are two reports related to bulkhead support construction entitled: (i) TB4 Pilot Study Observations and Future Design Impacts: Conventional Pile Installation Methods; and (ii) TB4 Pilot Study Observations and Future Design Impacts: Giken Trial. These reports provide detailed observations in support of the following key conclusions:

1) The TB4 Pilot Study has shown that conventional sheet pile installation equipment, including vibratory hammers and impact hammers, have caused adverse structural damage to upland structures along the Canal. The degree of damage is a function of distance from pile driving, the foundation of the adjacent structure, and initial condition of the structure. The subsurface conditions of TB4, which are similar to the rest of the Canal, demonstrated high sensitivity to construction induced vibrations as evidenced by settlement and displacement of the existing bulkheads up to 40 ft away from pile driving activities despite not exceeding the low vibration criteria established. It is recommended that conventional sheet pile installation equipment not be used within 40 ft of structures sensitive to settlement and/or displacement.

2) Sheet pile installation with the silent press exhibited a lower potential for causing damage than conventional pile driving methods, but some risk of damage to existing bulkheads and upland structures still exists. In general, minimal vibrations

and upland movements were observed with the silent press operation, but on one occasion, several inches of bulkhead movement was observed during operation. Additionally, the silent press equipment requires more space for implementation, thus limiting which properties are suitable for sheet pile installation with the equipment (i.e., properties with buildings immediately adjacent to the bulkhead may not have enough space for the silent press to operate).

3) Preconstruction structural assessments must be conducted as part of the design process to identify structures potentially sensitive to soil displacement and vibrations, establish construction performance criteria that can influence sheet pile construction methodologies, and assess the need for support systems for existing structures prior to sheet pile driving. As part of the structural assessments, the condition of the existing bulkhead should be documented including any battering of the bulkhead face which may require the sheet piles to be offset. Property access must be secured well in advance to allow for preconstruction assessments to be completed as part of the design process, prior to contractor bidding and mobilization. Finally, time should be provided to allow for additional, more detailed geotechnical/structural investigations as needed.

4) Alternate bulkhead support approaches need to be available as options at bulkheads associated with sensitive structures where conventional or press installation is precluded. Alternative bulkhead support approaches can include an offset of dredge limits around critical structures, buttressing, slotted excavation, or soil stabilization.

5) There is a clear advantage for property owners, who have unique knowledge of their properties and planned future uses, to execute bulkhead replacements on their properties. Property owners will be able to better control bulkhead design and construction methods that meet their immediate and long-term needs. Furthermore, with the availability of upland access, bulkhead supports can include anchorage which would allow for shorter and lighter sheet piles than is necessary for cantilevered bulkhead support systems, thus reducing the required size of equipment and construction related vibrations. Property owners would need to be provided with details about the proposed dredging and in-situ stabilization (ISS) activities near their property (50 ft) so that the bulkhead replacements can be designed for the critical loading conditions created by the remedial action construction. Overall, there is less risk with property owners replacing their own bulkheads.

Additional observations and potential considerations in future phases of the project related to sheet pile installation can be found in the reports as Attachments A and B.

DISTRIBUTION OF DEBRIS

As described in Attachment B, the presence of debris limits the effectiveness of pile installation with both the press pile method and conventional pile driving methods. Based on the observations, the results of previous debris surveys were reviewed to identify areas where high concentrations of debris can be expected. The surveys show large individual debris targets and debris fields, which are defined as areas with a large density of debris where individual debris pieces cannot be distinguished. The surveys represent near-surface (less than 2 ft) conditions and additional debris may be found deeper in the sediment column. In addition to the surveys, areas were identified where a high likelihood of encountering debris can be expected; these areas include street ends, bridges, and areas of known failed bulkheads. The debris distribution figures for the Canal are included in Attachment C.

Based on experiences from TB4 and evaluation of the figures in Attachment C, debris is expected to be encountered throughout the Canal, at various depths in the sediment column, and with an increased likelihood at numerous locations. Large pieces of obstructive debris are expected to be common near bulkheads where equipment and materials can more easily end up in the Canal.

The likelihood of encountering debris will complicate the utility of the Giken (and more conventional methods) and additional measures may be needed to improve performance where practical. In areas of dense debris prohibiting complete sheet pile installation, contingency measures may be necessary to bolster bulkhead support. To reduce the potential for debris-related issues during sheet pile implementation, more proactive measures such as trenching along the proposed sheet pile alignment should be considered. Such approaches require thorough evaluation since they lead to greater unsupported lengths of existing bulkheads.

* * * * *

ATTACHMENT A

TB4 PILOT STUDY OBSERVATIONS AND FUTURE DESIGN IMPACTS:

CONVENTIONAL PILE INSTALLATION METHODS

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Attachment A

TB4 Pilot Study Observations and Future Design Impacts:

Conventional Pile Installation Methods

This report has been prepared by the Gowanus Canal Remedial Design Group (RD Group) to document information gathered during the 4th Street Turning Basin (TB4) Pilot Study that should be considered during subsequent phases of the design and implementation of the Gowanus Canal (Canal) remedy. Per EPA's request at a technical meeting on October 19, 2017, the RD Group will provide observations from the TB4 Pilot Study to EPA in this format on a periodic basis.

The TB4 Pilot Study information has been categorized into different elements of the TB4 Pilot Study design and implementation. This memo provides observations from the time period from October 2017 through March 2018. Field work conducted in this time period was focused primarily on bulkhead support installation with conventional driving methods (i.e., vibratory hammer and impact hammer).

CONVENTIONAL SHEET PILE INSTALLATION

The TB4 Pilot Study explored the use of a cantilevered sheet pile wall system to provide temporary support of the existing bulkheads in TB4 to facilitate dredging and capping operations. The existing bulkheads ranged from fair to poor condition and consisted of timber crib bulkhead and anchored sheet pile construction types. Sheet pile walls with anchorage are the typical bulkhead replacement system used by private property owners along the Canal. A sheet pile wall with deadman tie rods would require excavation of the supported bulkhead and property. A sheet pile wall with drilled tieback anchors would require anchors to extend underneath existing structures. A cantilevered wall system does not require external support from anchors and was thus presumed to minimize the potential for disruption of upland properties, as well as alleviate some access concerns.

The conventional hammers for sheet pile installation include using vibratory hammers and/or impact hammers. These hammers can provide for efficient sheet pile installation through a wide variety of ground conditions and environments. Several conventional sheet pile techniques and methodologies were attempted along TB4, including vibratory pile installation, hydraulic hammer installation, use of "gang" and "pitch and drive" pile driving methods, and driving sheet piles in pairs and as single sheets. The use of these construction techniques and equipment is considered industry standard and were used for recent bulkhead replacement projects along the Canal conducted by private property owners; indeed, both types of hammers were also suggested as the appropriate construction approach by other local knowledgeable contractors[1]. However, these hammers are prone to creating vibrations that can adversely impact the nearby environment.

It is likely that the subsurface layers at and near the Canal, particularly the organic sediments and glacial deposits, are sensitive to vibrations and subject to consolidation, which manifests as movements observed at the surface. The vibrations generated during the installation of long, heavy sheet piles required for the cantilevered bulkhead support system were greater than the vibrations generated for conventional bulkhead systems installed along the Canal.

Vibration limits were set at 0.4 in/sec on peak particle velocity (PPV) and 0.1g on peak particle acceleration (PPA) to prevent structural damage directly caused by vibrations and settlement induced vibration, as detailed in the EPA-approved 100% design package for TB4. These limits were set at 15 ft from construction and at structures (whichever was closer). Despite observing vibrations below the specified vibration limits, each installation method caused movements and settlement of the existing bulkhead and nearby structures within approximately 40 feet of the operations. Throughout the use of vibratory and impact hammers, an acceptable level of vibrations that did not cause settlement or lateral displacement was not observed and therefore, revised vibration limits could not be established. Instead, it is strongly recommended that vibratory and impact hammers not be used within 40 ft of utilities or structures sensitive to settlement or lateral movement.

In contrast, elsewhere in TB4 and along the Canal, property owners have installed anchored steel sheet pile systems that utilized shorter and lighter sheets than cantilevered systems and usually involved redevelopment of the site within 40 ft of the bulkhead face, or buildings were not present within 40 ft of the canal. During installation of the shorter sheets, vibration related issues were not documented and any movement within 40 ft of the wall was in an area that was ultimately redeveloped.

The movements impacted upland conditions and created multiple complications for the project. Subsurface conditions, bulkhead conditions, and proximity and integrity of structures similar to those observed in TB4 are expected throughout the Canal. As in TB4, the RD Group does not own or control any of the properties adjacent to the Canal and cannot mitigate or accept structural damage in the same way property owners working on their own property can. Therefore, less conventional pile installation methods, alternative bulkhead support strategies, and/or alternative

[1] EPA directed meetings with local contractors experienced on the Gowanus Canal to get input on methods routinely used for bulkhead installation. Meetings with three contractors were held in December 2017, and EPA participated in one of the meetings.

remedial approaches will be necessary in many areas to reduce construction induced vibrations and the significant project consequences that result.

Provided below is a discussion of specific lessons learned and potential additional considerations to move the overall project forward.

- **The existing infrastructure and buildings along the Canal are sensitive to vibrations and settlement and require detailed structural review to be performed prior to the final design of bulkhead support systems.** Existing, aging infrastructure and buildings along the Canal must be surveyed prior to work commencing to understand the existing structural condition of building(s) and the relative sensitivity to foundation vibrations and settlement. Any schedule for design and/or construction must reflect this surveying process.

  The northwest portion of the building at 386 3rd Ave is an example of a structure in pre-existing disrepair whose conditions appear to have been exacerbated by installation-based vibration and settlement. Expansion of existing cracks and settlement have been observed in a portion of the building since operations were conducted immediately adjacent to the structure.

  The Whole Foods property is an example of how modern construction can be sensitive to vibrations. The structure was redeveloped in 2012 using controlled fill placement. Before sheet pile installation, it was observed that the promenade exhibited signs of settlement relative to the Whole Foods building. It is not clear as to the exact cause of the settlements observed prior to sheet pile installation, or whether the settlements were ongoing immediately prior to sheet pile installation. Vibrations generated by the sheet pile installation appeared to accelerate the settlement and caused movement of the bulkhead supporting the esplanade.

  These examples demonstrate that a comprehensive, detailed assessment of building and infrastructure structural conditions should be conducted along the Canal to inform the design, including alternatives to bulkhead support other than using sheet piles. Characteristics of concern include, but are not limited to, age of construction, type of construction, foundation type, construction methods, type of structure, and apparent allowance for movement. The assessments should be performed with consideration of a design basis agreed upon between EPA and the RD Group.

Private property access must be procured in advance of bulkhead design to conduct the detailed assessments of buildings and associated structures. This will require EPA taking a critical lead role with the property owners to gain access in a timely manner. Time may also be needed to allow for additional, more detailed geotechnical/structural investigations. Further coordination is needed among the RD Group, EPA, and property owners regarding when and how to integrate building assessments and related activities into the overall project schedule.

- **Real time surveying and vibration monitoring of the bulkheads and adjacent structures can help limit the potential for exceeding threshold limits.** Settlements and lateral displacements at and away from the bulkhead face may occur at vibration levels below the commonly accepted industry standard vibration criteria, depending on site conditions. Optical survey monitoring in a grid-type pattern adjacent to the work area coupled with vibration monitoring are needed to document potential construction-related impacts. It is recommended that total station surveying (TSS) be used to provide near real-time survey monitoring of the work area. The survey markers used with the TSS can be susceptible to weather (wind) and obstructions; therefore, periodic field survey measurements are recommended to confirm observations derived from TSS readings. The TSS system also requires several reference stations that should be completely stationary. These stationary locations should be set on locations and structures that are significantly beyond the area of influence of pile driving, which can be as far as 40 ft. It is recommended that the TSS be set up a minimum one week before the start of work to get baseline measurements and to observe if there is any potential ongoing creep along the bulkheads. Vibration monitoring should also be done in real time and include an alert system that notifies field personnel when threshold vibration levels are exceeded so that proper corrective action can be taken. Alert vibration thresholds should be lower than the allowable vibration limits to better manage vibration and reduce the potential for exceedances.

- **When pile driving near structures, an on-site structural engineer can help maintain project flow.** Conventional pile driving methods can cause movements that lead to damage of nearby existing structures. It was observed that structures within 30 to 40 ft of pile driving activities (like Dykes Lumber) showed signs of movement. Therefore, when pile driving within 40 ft of existing structures, such as buildings or bridges, a structural engineer should be on site to provide real time evaluation of the conditions of the structures. This can help limit structural damage, allow for early identification of structural issues, and reduce turnaround time for structural evaluations.

- **At least two points of fixation at different heights must be maintained during initial pile installation along an alignment.** Only one point of contact was maintained during the installation of the first TB4 pile and shifting of the sheet pile during installation resulted in a near-miss safety incident. As a corrective measure, at least two points of fixation must be maintained at all times during installation of the first pile in an alignment. Subsequent piles can use installed piles as a second point of contact.

- **The batter of the existing bulkheads must be considered for bulkhead support design and implementation.** Some bulkheads in TB4 were battered and the toe of the sheet was further into the Canal than the top of the sheet located at ground surface. As a result, an offset placement of support sheets was needed. For example, a portion of the Whole Foods bulkhead support was offset 72 inches from the existing bulkhead because the sheet pile face of the existing bulkhead had an incline greater than 10 degrees, leading to issues of realignment and soft sediment removal. The design process should evaluate the potential for offset because battered steel sheet piles and battered face timber bulkheads will require that the offset of the bulkhead support be further into the Canal.

- **Vibratory hammers implemented with best management practices can still create vibrations that cause consolidation of existing subgrade materials along the Canal allowing for movement of existing bulkheads.** During the bulkhead support installation of the TB4 Pilot Study, two different models of the vibration hammer were used to install bulkhead support sheet piles. The two models used were the 1) APE Model 170 Variable Moment Vibratory Driver Extractor (170VM), and 2) APE Model 250 Variable Moment Vibratory Driver Extractor (250VM). The maximum drive force of each hammer is 134 tons and 269 tons, respectively. Generally speaking, the vibratory hammer can effectively and efficiently drive a sheet pile pair to target elevation in TB4 and may be an effective tool along the Canal in certain, limited conditions. However, the vibratory hammer does create notable levels of vibrations within 25 ft of pile driving. Both the 250VM and 170VM vibratory hammers were used for the TB4 pile installation along portions of Whole Foods' bulkhead and 386 3rd Avenue's bulkhead.

  Vibrations from pile driving were monitored in real time. The frequency and force of the vibratory hammer was adjusted to limit the induced vibrations. Despite controlling the hammer and maintaining induced vibrations within target limits, at all locations adjacent to vibratory pile driving, settlement of the existing bulkhead and the development of cracks behind the existing bulkheads were observed. The rate of settlement and movement was greatest at the time of and shortly after the induced vibrations; however, they continued at a deaccelerated rate for weeks after driving. Furthermore, it was observed that the zone of influence from the vibrations along the line of sheet pile installation is greater than 30 ft, as shown in Figure 1 and Figure 2. Monitoring point (MP) MP-139 and MP-139B are located on the existing bulkhead front edge and in the middle of the existing bulkhead, respectively. These points are located in the parking lot at 386 3rd Avenue. MP-139 is at the bulkhead face and MP-139B is approximately 10 ft behind the face. It appeared that movements continued for some time (on the order of several weeks to a couple months) after nearby pile installation is complete, indicative of material consolidation, possibly caused by vibration induced excess pore pressures. It was unclear within which soil units the movement was occurring.

Based on these observations, vibratory pile driving should be avoided along the Canal in areas within 40 ft of sensitive structures and utilities that cannot allow for several inches of potential lateral displacement and settlement. This criterion may limit the use of conventional pile driving methods to a select few locations along the Canal, requiring that alternative pile driving methodology be implemented.

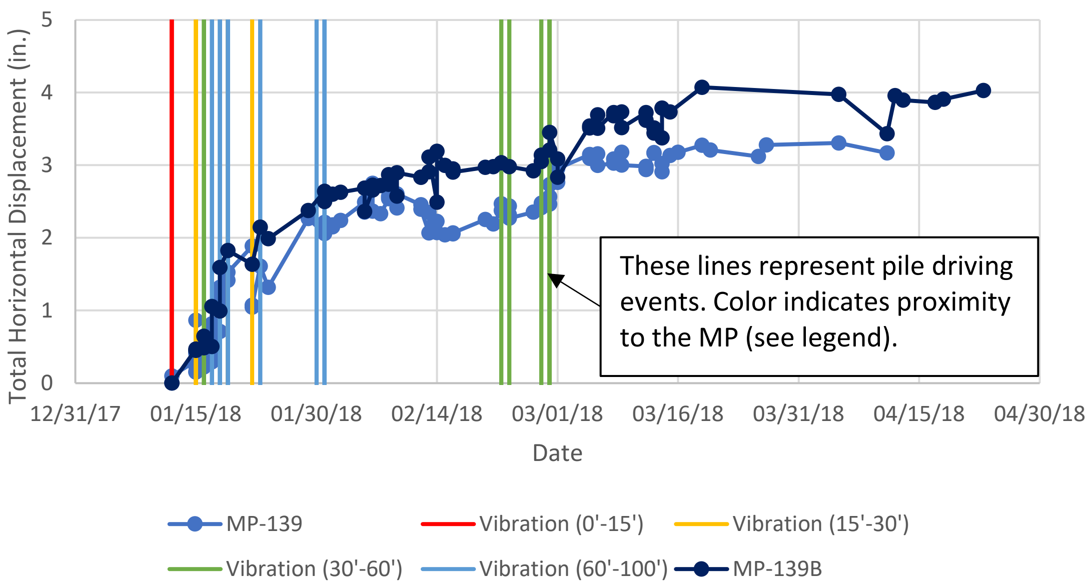

Figure 1. Measured Lateral Displacement (towards TB4) at MP-139 and MP-139B during Vibratory Hammer Driving

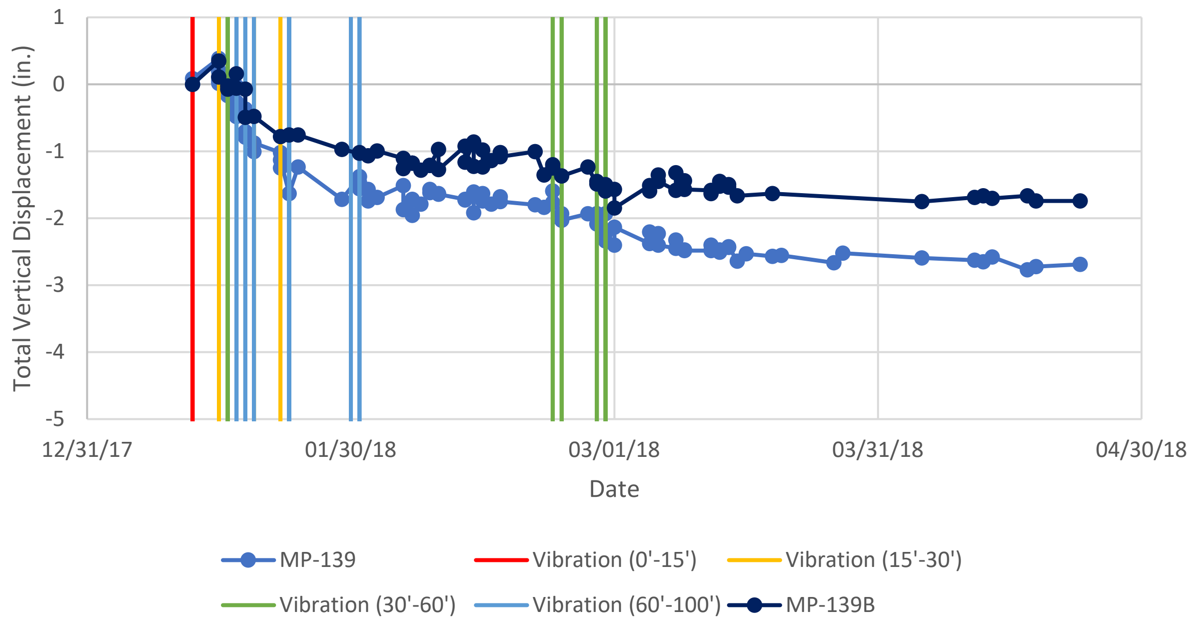

Figure 2. Measured Vertical Displacement at MP-139 and MP-139b during Vibratory Hammer Driving

- **Hydraulic impact hammers create vibrations that can cause movement of existing bulkheads.** A hydraulic impact hammer (Dawson HPH2400) was utilized in an attempt to reduce pile installation noise and vibrations. The hammer was tested at various stroke heights to identify the most efficient method of pile driving that did not cause excess vibrations. At a low stroke height, the hammer could not effectively drive the sheet piles through the glacial deposits which underlay the native alluvial sediments. At the mid-range stroke height, the sheet piles could be driven to target depths; however, settlement and displacement of the existing bulkhead was observed. Movements at the optical survey markers were similar in behavior to what was observed during vibratory pile driving, as shown in Figure 3 and Figure 4. As was the case for vibratory driving, it appeared that movements continue for some time after pile driving and it was unclear as to within which soil unit(s) movements were occurring. Structures within 20 ft of the pile driving, including those both in fair and poor condition, also developed signs of movement. The high number of blow counts required to drive the sheets caused the tops of the sheets piles to crush and disfigure. Additionally, the contractor had less control on the location and alignment of the piles installed and therefore required additional falsework as compared to vibratory sheet pile installation, as shown in Figure 5. The additional falsework reduced the production rate for sheet pile installation. Based on the observations made during the Pilot Study, hydraulic impact hammering should not be used for sheet pile installation within 40 ft of structures, and if used, requires extra falsework as compared to vibratory hammers to better maintain pile alignment and location.

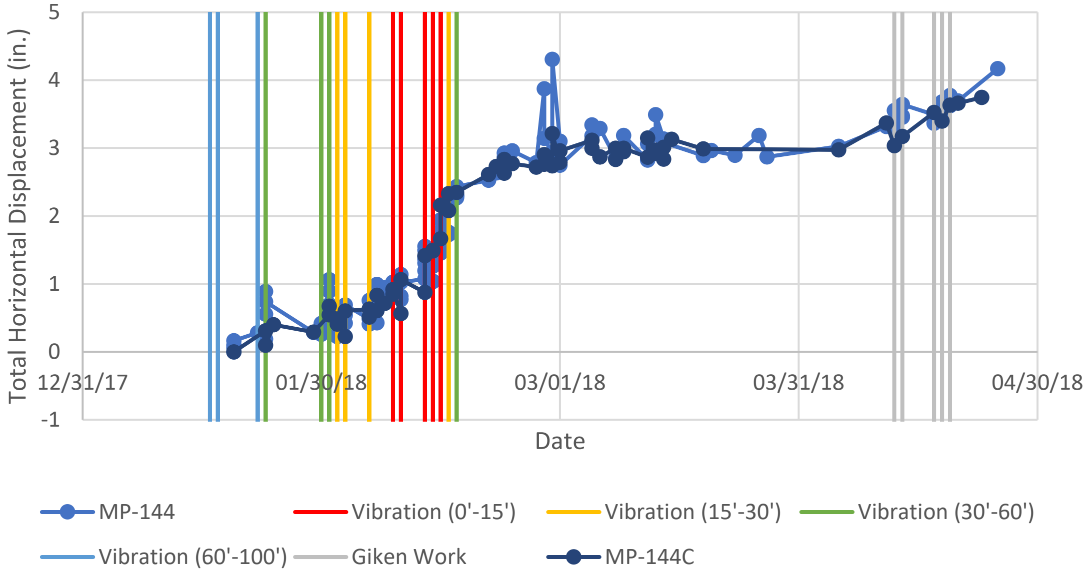

Figure 3. Measured Lateral Displacement at MP-144 and MP-144c during Impact Hammer Driving

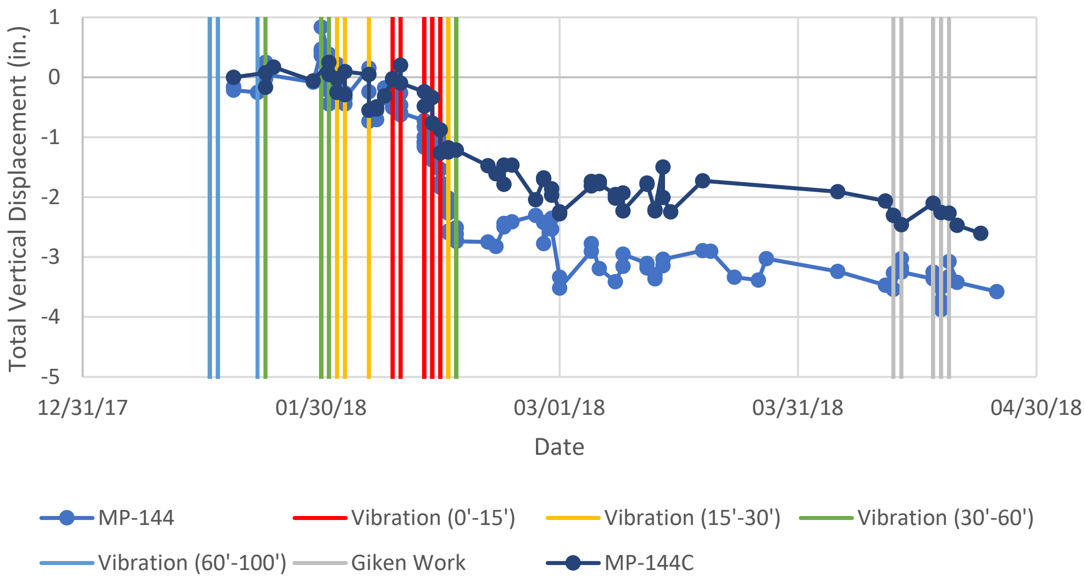

Figure 4. Measured Vertical Displacement at MP-144 and MP-144c during Impact Hammer Driving

Figure 5. Example of Impact Hammer Pile Driving

- **A combination of vibratory and impact hammers is not effective in limiting vibrations and movements.** A combination of vibratory hammer and impact hammer was implemented as an attempted approach to limit vibrations. Various combinations of vibratory frequency and hammer stroke height were attempted; however, no combination demonstrated a meaningful reduction in vibrations or observable reduction in settlement/movements of the existing bulkheads. Therefore, it is not recommended to use a combination of vibratory and impact hammers for sheet pile installation in place of using a single method.

- **Debris and dense soils can prevent piles from achieving target tip elevation.** When difficult driving conditions were encountered, the total duration of driving increased and sometimes driving refusal was realized. Longer driving durations led to increased durations of vibration and increased potential disturbance of the surrounding soils. For example, from Sta. 7+64 to Sta. 7+26 (Whole Foods) several sheet pile pairs encountered driving refusal within the deeper glacial deposits and often reached refusal at depths greater than 10 feet above the target tip elevation. Initial pile driving was performed with the 250VM and then the equipment was switched to the smaller 170VM. The 170VM was generally able to advance sheet piles to the required tip elevations; however, it was observed to have a decreased ability to break through dense soil layers and obstructions than the 250VM. While the larger 250VM could more effectively install the sheet piles, it generated higher levels of vibrations and noise during driving. In areas with high potential for debris or shallow dense zones of gravel, larger vibratory hammer is recommended but only if there are no vibration sensitive bulkheads or structures nearby (less than 40 ft).

- **The panel driving approach should be avoided.** Use of the panel driving approach with either the 250VM or the 170VM led to noise exceedances and greater potential for upland disruptions. The panel driving approach involves setting up to four pile pairs in a line with the first (king pile) and last (queen pile) driven down about halfway. Then the gang piles (those in-between the king and queen piles) are driven down in sequence. Once the panel is about half-way down, the piles are driven to target depth in a stepped sequence. An example of panel driving is shown in Figure 6. The approach provides better control over pile alignment and improves drivability past obstructions and hard ground compared to installation of single pairs. However, the large number of sheets suspended in the air led to noise levels exceeding the suggested allowable criteria as the sheets rattled in the interlocks during driving. Noise levels were reduced by modifying the installation approach to a single pair of sheets and using the smaller, 170VM.

Figure 6. Example of Panel Pile Driving

- **Pitch and drive method requires careful execution.** EPA directed following the "pitch and drive" method for driving sheet piles, with piles being driven one at a time instead of in pairs. An example of the pitch and drive method is shown in **Figure *7***. In the photo, the leading pile is being driven while the previously driven piles are held together and bolted to the guide waler beam. This method involved driving one sheet at a time to target depth in sequence along the wall alignment. This method helped reduce noise during installation but not to decibel levels below target; however, it provided less control on sheet pile alignment. Several sheet piles had to be removed and reset to maintain pile alignment. Pulling sheet piles and redriving caused additional vibrations that induced additional settlement and displacement of existing bulkheads. The areas of greatest settlement have been observed in areas with the longest durations of driving. To limit vibration exposure, piles cannot be allowed to go out of alignment thus requiring to be reset; therefore, extra care and falsework should be required to limit the potential for pile misalignment.

Figure 7. Example of Pitch and Drive Pile Installation

- **The long and heavy sheet piles required for a cantilevered wall are logistically more challenging to install and installation can impact a larger area than the sheet piles necessary for an anchored wall.** The sheet piles required to provide temporary cantilevered support to the existing bulkheads are on average 50% longer (65 ft vs. 45 ft length) and weigh 80% more on a per sheet basis because the sheets are thicker and longer than the typical sheet piles used as part of a permanent anchored bulkhead replacement systems along the Canal. The size and weight of cantilevered sheets created logistical challenges.

  These larger sheets were not as readily available as the more common smaller sheets and required more lead time for production, on the order of months as compared to weeks. Compared to the typical operations used during sheet pile installation for permanent bulkhead work, the heavier and longer cantilevered sheets require larger equipment that can be difficult to maneuver around the narrow Canal. Effectively driving the larger sheets to the deep and dense target soil strata required larger hammers operating at high vibration energy levels. The deep depth to which the piles must be driven created a wider zone of influence from the vibrations. Therefore, the deep pile driving coupled with higher driving energy created a higher potential to impact a larger area on the upland sides of the Canal.

In areas that require a large cantilevered sheet pile, it is recommended that alternative methods to the conventional pile driving be implemented, such as the press pile method and the auger and press method. However, the sheet piles require deep embedment and may require driving through a stratum of dense gravel which can inhibit the sheet pile installation rate (see Attachment B).

Alternatively, it is recommended that in areas that can accommodate an anchored wall and where necessary additional access can be obtained, that it be considered instead of a cantilevered system because conventional construction methods may be implementable.

Figure 8. Photo of the Crane and Barges Necessary to Perform the Sheet Pile Installation

ATTACHMENT B

TB4 PILOT STUDY OBSERVATIONS AND FUTURE DESIGN IMPACTS:

GIKEN TRIAL

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Attachment B

TB4 Pilot Study Observations and Future Design Impacts:

Giken Trial

This report has been prepared by the Gowanus Canal Remedial Design Group (RD Group) to document information gathered during the 4th Street Turning Basin (TB4) Pilot Study that should be considered during subsequent phases of the design and implementation of the Gowanus Canal (Canal) remedy. Per EPA's request at a technical meeting on October 19, 2017, the RD Group will provide observations from the TB4 Pilot Study to EPA in this format on a periodic basis.

The TB4 Pilot Study information has been categorized into different elements of the TB4 Pilot Study design and implementation. This report provides observations from the period from March 26, 2017 through April 25, 2018. Field work conducted during this period was focused primarily on bulkhead support installation and the Giken Press Trial. Pile installation records are summarized in Table A1.

GIKEN PRESS TRIAL

Sheet pile driving in TB4 using a vibratory hammer and an impact hammer caused movement and settlement at existing bulkheads and buildings within 40 feet of the operations (observations from conventional hammers are included in Attachment A). In response to observations of movement and settlement with conventional sheet pile installation methods (vibratory hammer and impact hammer), silent press pile equipment (Giken) was brought on site as part of a trial study to investigate its effectiveness in installing sheet piles without adversely impacting upland structures. As part of the trial, two methods were investigated, (i) the press method and (ii) the auger and press method. For the press method, the Giken machine pressed the sheet pile down to target elevation without the use of any additional attachments. For the auger and press method, the Giken machine augered and pressed the sheet pile to advance it to target tip elevation. The press method can be effective in areas with no debris or dense gravel layers that could inhibit installation. The auger method can allow for installation through dense gravel layers, though it is considerably slower and does not appear to be more effective than the press method when debris is present.

The Giken trial proved generally successful in installing the remainder of the TB4 bulkhead supports with marked reductions in noise and vibrations compared to the conventional approaches, but challenges were identified which need to be incorporated into the design for the Canal. The main challenges identified are that the equipment has spatial limitations which will prohibit its use in certain areas along the Canal, it is vulnerable to buried debris interfering with the installation, there are logistic considerations that need to be accounted for (such as starter pile installation and alignment limitations) when laying out sheet piling to be driven with the equipment, and installation process may still result in movements of adjacent bulkheads. While the press method can be a viable tool to reduce construction vibrations and limit the potential for vibration caused movements of upland structures during sheet pile installation and should be considered for future use, there are certain portions of the Canal that may be suitable for this technology and may require an alternative bulkhead support strategy.

Table 1, presented below, is a summary of the observed strengths and weakness of the press method, and the auger and press method. Table 2 is a comparison of the conventional sheet pile installation equipment and the silent press with and without the auger attachment.

Table 1. Strength and Limitations of the Press Method, Auger and Press Method

Strengths	Limitations
Low noise machine, less disruptive to the community.	Low production rate relative to conventional pile driving. Very low production rate when working with the auger attachment.
Generates low vibrations and can be used to limit the potential for vibration caused movements.	Piles often cannot be pressed through obstructions (whereas vibratory and impact hammers can be used to break through some obstructions).
Can install sheet piles without formwork.	Requires more clearance space around the equipment than is needed for conventional hammers.
Can install sheet piles with high accuracy and precision relative to location and plumbness.	Requires starter piles to work from as initial reaction piles. These may need conventional hammers for installation or they can be installed from a barge which can take a couple days for a starter pair.
Auger attachment can be used to assist in advancing piles through dense.	Not as maneuverable as vibratory or impact hammers because the machine sits on two pile pairs and pushes the third, and the piles can have a limited skew.

Table 2. Comparison of Sheet Pile Installation Equipment, Conventional vs. Press Pile

Method	Noise[3]	Vibration[4]	Installation Precision[5]	Installation Rate[6]	Hammer Flexibility[7]	Hard Ground[8]	Pile Damage[9]
Vibratory Hammer	High	High	Moderate	High (8-14 pairs/day)	High	Moderate	Moderate
Impact Hammer	High	High	Low	Moderate (6-12 pairs/day)	High	Moderate	High
Press	Low	Low	High	Moderate (6-8 pairs/day)	Low	Low	Low
Auger+ Press	Low	Low	High	Low (2-3 pairs/day)	Low	High	Low

Notes

1) Qualitative characterizations of "high", "moderate", and "low" are relative between the methods presented in the table. They do not correlate to a range of values.
2) Highlighted cells indicate preferred method for a given category.
3) Noise: Magnitude of noise the equipment produces. Low is favorable.
4) Vibration: Amount of vibrations the equipment produces during driving. Low is favorable.
5) Installation Precision: Accuracy and control over the plumbness and location of the installed pile. High is favorable.
6) Installation Rate: The rate for driving sheet piles. High is favorable.
7) Hammer Flexibility: The maneuverability of the equipment and the ability to install sheet piles in various configurations. High is favorable
8) Hard Ground: The ability for the equipment to drive sheet piles through natural, hard ground conditions. High is favorable.
9) Pile Damage: The potential that the equipment will damage the sheet piles during installation. Low is favorable.

Provided below is a discussion of specific lessons learned from the Giken operations in TB4 and additional suggestions to consider for later phases of work along the Canal.

- **The Giken equipment requires open space to operate**. The machine requires at least five ft of open space on either side of a pile so that a platform can be used around the machine's head to provide crew access for setting piles through the machine's grip. See Figure 1. Furthermore, the machine's grips need two to three ft of clearance on either side to be able to maneuver around the pile tops and must also be kept away from the Canal's brackish water because the water can cause corrosion of the sensitive grips. The best approach for providing adequate space for the equipment is to set the pile tops at an elevation high enough that the top of the existing bulkhead can be cleared by the machine's grips.

  The spatial requirements of the Giken equipment means that the Giken will not be able to install piles immediately adjacent to existing bulkheads that have structures or walls along the bulkhead edge; an example of such a situation is presented in Figure 2. In such situations, an offset up to six feet from the existing bulkhead will be required with the Giken, depending on the upland obstructions. It is estimated that 14% of bulkheads along the Canal cannot be directly accessed with the Giken.

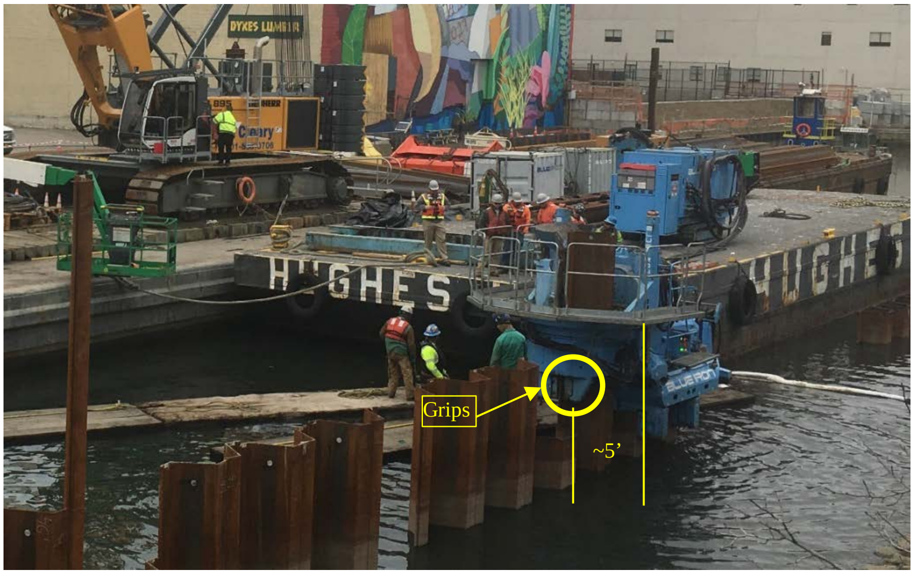

Figure 1. Photo of Giken Set on Sheet Pile

Figure 2. Photo of Property in RTA2 with Structure Immediately on and Cantilevering over Existing Bulkhead

- **The press method can be effective along the Canal.** The Giken is capable of directly pressing the sheet piles into the native sediments using existing, pre-installed sheets as reactions. The Giken press requires a minimum of two sheet pile pairs installed to target tip elevation to act as a reaction. These piles are referred to as "starter sheets." The starter sheets may be installed with a vibratory hammer. However, in areas with soil sensitive to vibrations, the starter piles may need to be installed by the press method from a barge, which is challenging and could take two to three workdays to complete. AZ36-700N sheet pile pairs were efficiently advanced (in 20 to 30 minutes) 50 ft through soft sediment, native alluvial sediment, and shallow reaches of the glacial deposits in TB4 with less than 80 tons of downward force using the press method. Typically, at depths greater than elevation -45 NAVD88 in TB4, sheet pile advancement met resistance and advancement rates slowed down considerably to as low as one ft over five minutes, because downward forces greater than 80 tons were required to press the piles through a dense gravel layer existing within the glacial deposits. Advancement continued with the press method by modifying the approach by welding plates to the sheet piles to assist with the grips and prevent grip slippage. Welding these plates can take 20 minutes and may be required multiple times. Along the Canal, at deep depths where dense layers of gravel exist within the glacial deposits, the press method may not be viable, and the auger and press method may be necessary to achieve target tip elevations.

  The press method on average took approximately 60 minutes for complete installation, including welding grip plates (Table 3). A typical daily production rate of four to eight pile pairs (55 ft to 65 ft long each) a work day (eight to ten hours) can be expected, depending on pile lengths, driving conditions, and length of work days. These production rates assume good driving conditions and do not account for equipment maintenance or repairs, or other delays.

Table 3. Summary of Giken Installation Rates

Installation Method	Pile Pairs Installed	Observed Installation Time Range (min)		
Press	30	15	to	251
Auger + Press	6	55	to	190

- **The use of the auger-assisted Giken can be time consuming and challenging**. The Giken equipment can hold and maneuver a 40 ft long auger on its own; however, the project required the use of a nearly 90 ft auger because of the length of pile being installed in TB4. The 90 ft auger required crane support during drilling and maneuvering, as shown in Figure

3. Overall, during the installation of a single pile pair in TB4, an extra 60 to 90 minutes was necessary to maneuver the auger compared to the simpler press method, reducing production by at least 50%. This extra time is broken down as:

- Because of limited working space available in TB4, the same crane that supported the auger was required to also lift the sheet pile pair to be installed. This is a challenging maneuver that can take 15 minutes to complete.

- The auger and sheet pile pair must be welded to each other to ensure that the auger does not “walk” and advance away from the piles. Welding takes approximately 20 minutes.

- After a pile is installed the auger must be lowered before the Giken can proceed to the next position. Lowering and raising the auger can take 10 to 20 minutes each time (10 to 20 minutes for lifting and 10 to 20 minutes for bringing it back down).

- At the beginning of the work day with the auger, the auger hoses must be connected to the machine. This can take up to 20 minutes and is a required maneuver if the Giken machine needs to be lifted or moved.

Because of all the extra time associated with the auger, the auger and press method took on average approximately 130 minutes per pile pair for complete installation (Table 1). A typical daily production rate of three to four pile pairs (55 ft to 65 ft long each) a work day (eight to ten hours) can be expected, depending on pile lengths, driving conditions, and length of work days. These production rates assume good driving conditions and do not account for equipment maintenance or repairs, or other delays.

Figure 3. Photo of Crane Lifting Sheet Pile while Holding the Auger

- **The auger and press method can provide a more reliable installation for deeper piles passing through dense gravel layers as compared to the press method, unless hard obstructions are encountered.** The auger and press method was attempted in TB4 to advance the sheets through the hard and dense layers of gravel that existed below elevation -45 in TB4. The auger-assisted Giken was able to advance the sheets to embedment depths of -50 ft NAVD88 within one hour. In similar conditions, the press method could take longer because of the need to weld grips (typically 20 minutes each time and can require two iterations or more) to assist advancing. However, the auger tends to refuse on hard foreign objects and is susceptible to damage as noted above.

- **Debris can limit the effectiveness of the Giken**. Debris was encountered between piles 244 and 255 (six pile pairs) along bulkhead support stations 5+57 to 5+82. The debris prevented the Giken from achieving target tip elevations with the press method, therefore the auger and press method was implemented. Based on the pieces of debris recovered by the auger, the debris consisted of iron metal, rebar, and bricks. It is unclear the exact depth at which the obstructive material was initially encountered. Soft sediment dredging in TB4 has demonstrated that debris is located throughout the soft sediment column. The obstructions may have been encountered at more shallow depths and then were dragged to deeper elevations and into dense gravels where the obstruction became interlocked with the gravel, preventing continued pile advancement.

Metal obstructions damaged the auger head on multiple occasions. During installation of the six pile pairs, the auger head was severely damaged twice and required complete replacement; Figure 4 is an example of a damaged auger head. Auger head replacement represents a substantial delay in schedule as it can take about half a work day to remove and replace. It is not feasible to use the auger to drill and break down hard debris such as metal and concrete.

Furthermore, hard drilling has been observed to create vibrations at levels below the exceedance threshold but nevertheless measurable at nearby bulkheads and structures, potentially leading to incremental movement of the existing bulkhead. Vibration induced movements from hard augering were observed at monitoring point (MP) 104, near bulkhead support station 5+75 along the Whole Foods bulkhead. Lateral displacement and vertical displacement plots are shown on Figure 5 and Figure 6, respectively. Therefore, continued use of the auger is not recommended when hard grinding like drilling is encountered. Rather, augering should cease and the pile pair should be advanced to refusal by the press method.

During dredging of the soft sediment, debris of variable size was encountered over the full column depth of material, especially immediately adjacent to bulkheads. The extent of debris throughout the Canal coupled with the fact that small debris can be disruptive (depending on the installation method) makes it difficult to characterize the challenges and risks that debris presents before construction. Therefore, contingency measures may be required if early pile driving refusal is encountered. Contingency measures may include localized ground improvement with in-situ soil mixing or constructing a stabilization buttress.

Figure 4. Photo of a Damaged Auger Head

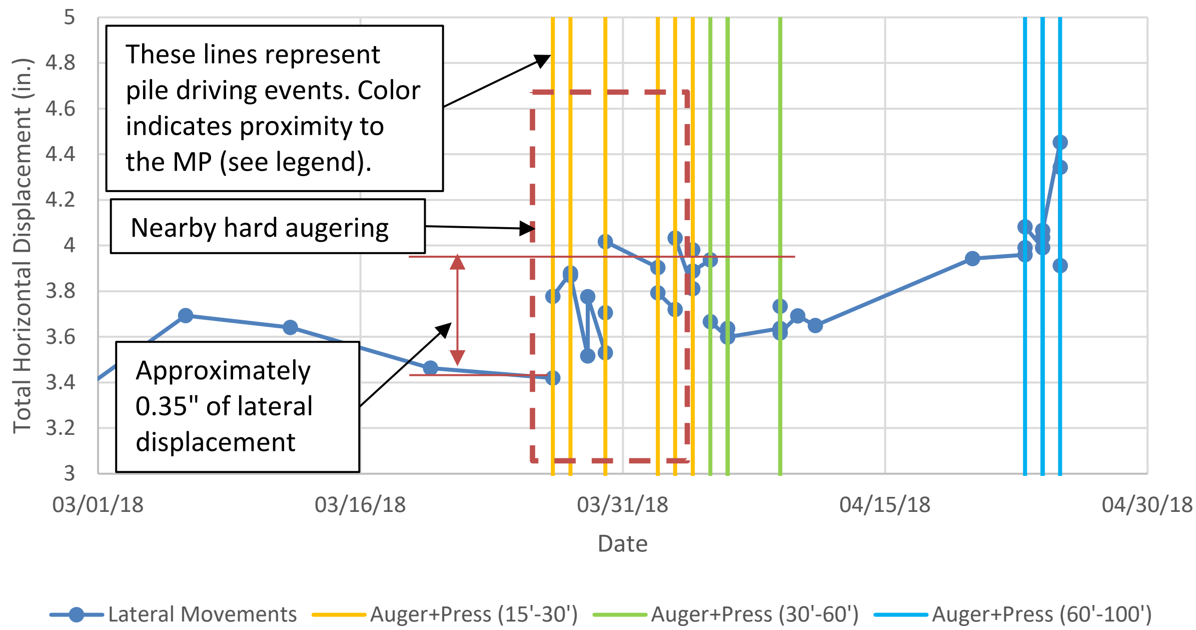

Figure 5. Measured Lateral Movements at MP-104 during Hard Augering

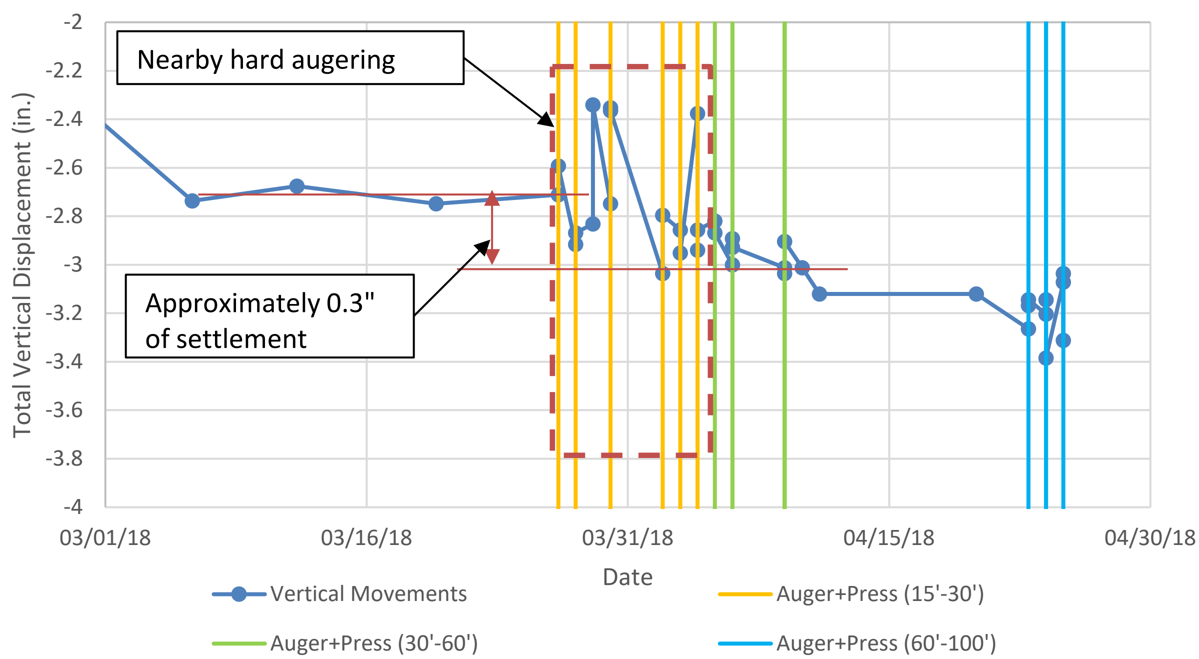

Figure 6. Measured Vertical Movements at MP-104 during Hard Augering

- **Verticality of the piles is critical for the Giken**. The piles for the bulkhead support in TB4 have a relatively long unsupported length and act as a cantilever. Therefore, any eccentricity from the Giken machine's weight acting on the top of the pile can destabilize the pile and the Giken machine may fall over. The piles must therefore be installed completely plumb so that the center of mass of the machine remains along the centerline of the sheet pile wall alignment. To ensure pile verticality some piles may need to be pulled and re-driven before accepted as installed, which may create schedule delays, especially in areas with deep seated debris that may cause the piles to deflect during driving.

- **The press method can cause movements of adjacent existing bulkheads.** Throughout installation, the press method produced less vibration than press and auger method; however, movements of existing bulkheads were still observed on occasion. During driving at Dykes Lumber movement was observed in both areas where existing piles were pulled and replaced, and in areas where piles were only replaced (no existing piles required removal). An example area of where only pile installation with the press method is shown in Figure 7. The measured movements are presented in Figure 8 and Figure 9 near MP-147. MP-147 and MP-147A represent optical survey points on the existing bulkhead and MP-16A represents a point on the Dykes Lumber structure's foundation. At these monitoring points it was observed that the existing bulkhead shifted downward and towards the Canal on April 18th. On this date, six pile pairs were pressed. The pile installation process observed on this date was similar or faster (lower resistance) than that observed on previous days, with no indication of encountered obstructions in shallow reaches and hard driving not being encountered until elevation -50 or deeper. Therefore, the mechanism and cause of the movement is unclear. Additional movements at points near MP-147 are shown in Figures 10 and 11.

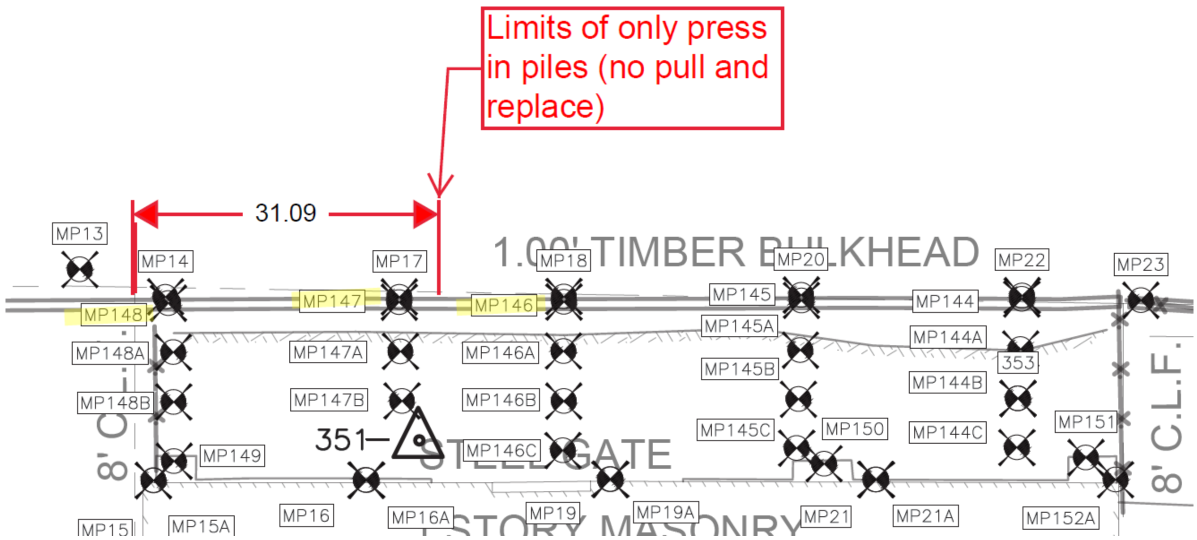

Figure 7. Monitoring Point Location Plan along Dykes Lumber

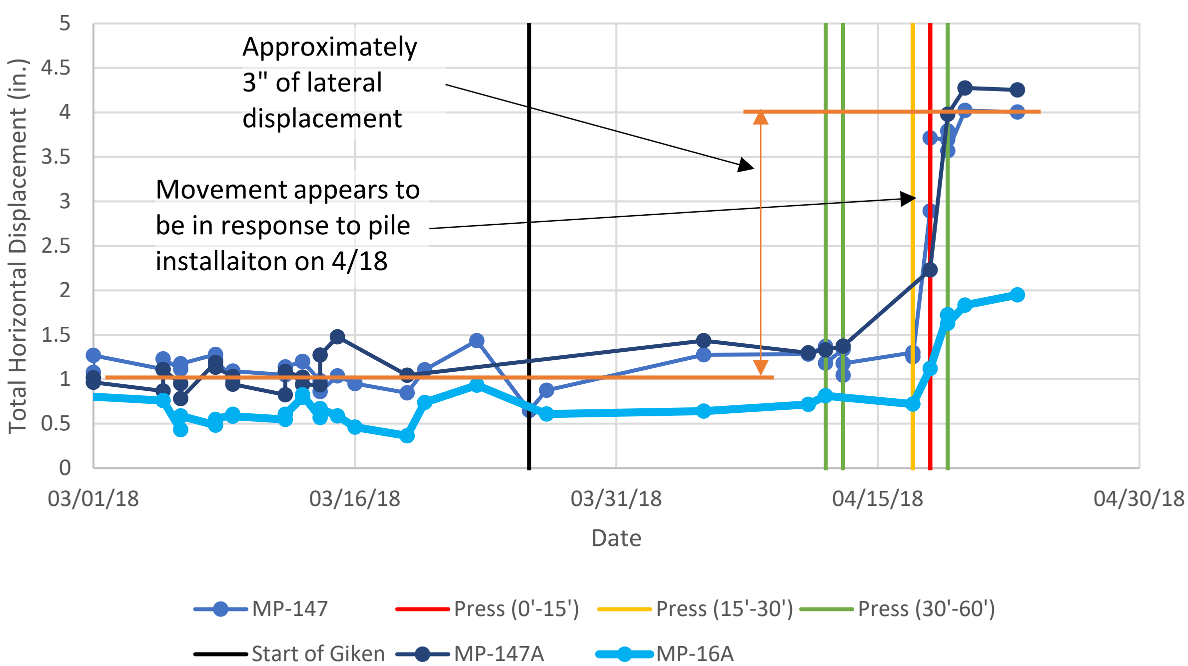

Figure 8. Recorded Lateral Movements during Giken Trial at MP-147

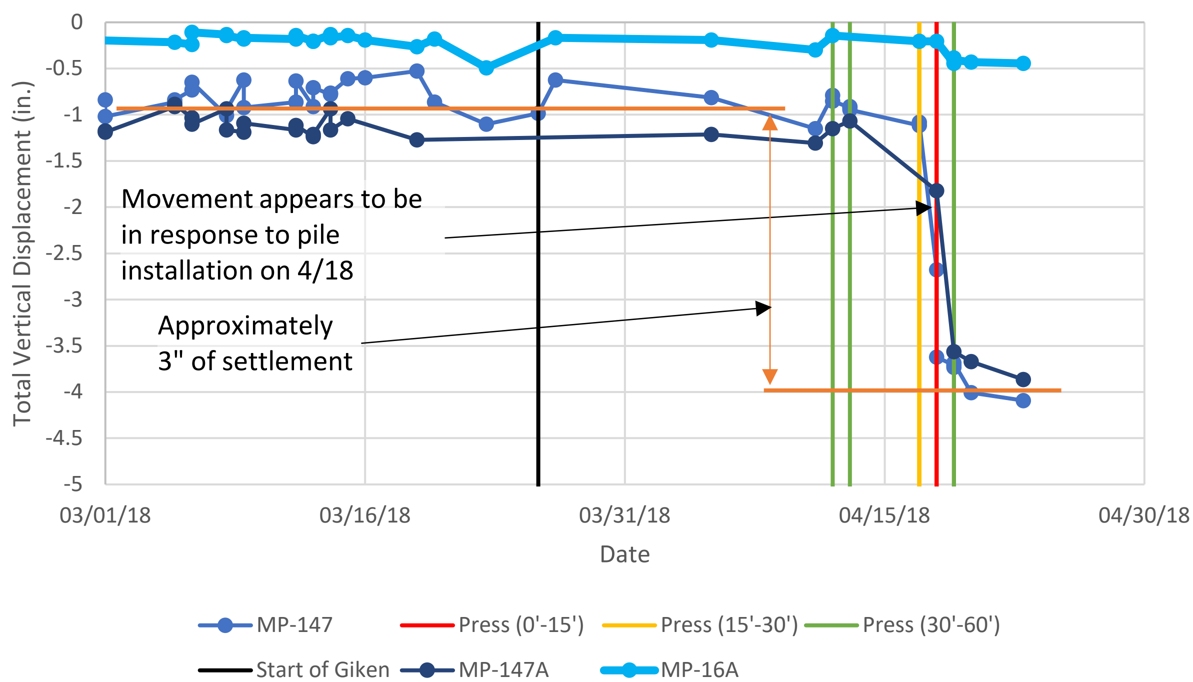

Figure 9. Recorded Vertical Movements during Giken Trial at MP-147

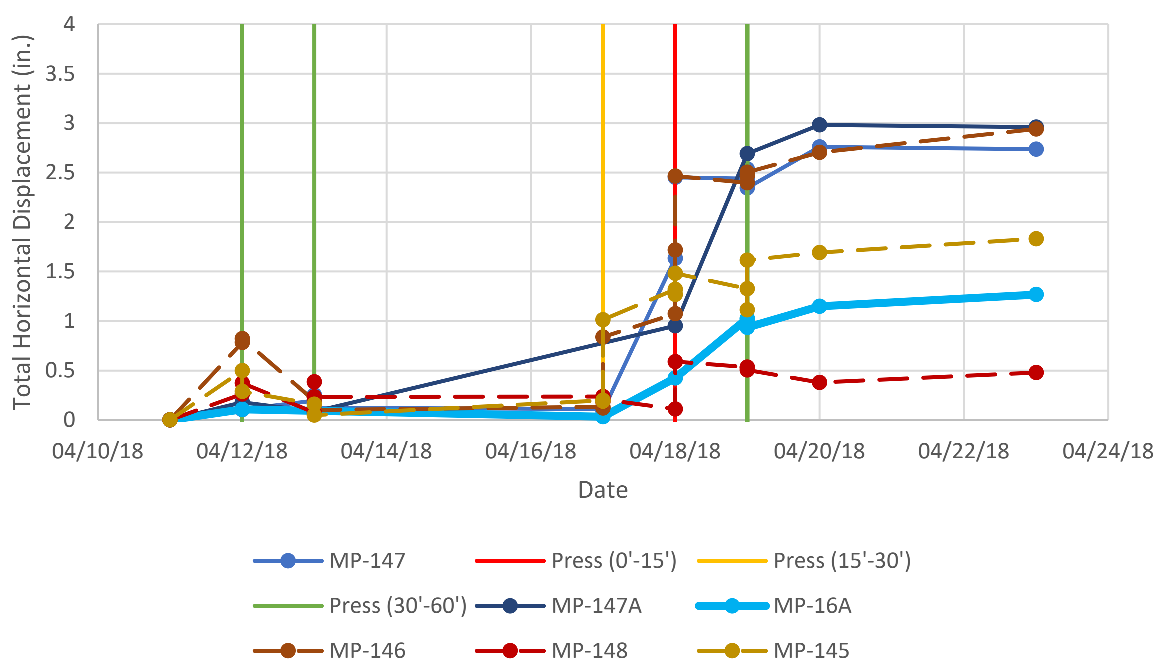

Figure 10: Recorded Lateral Movements during Giken Trial at and near MP-147

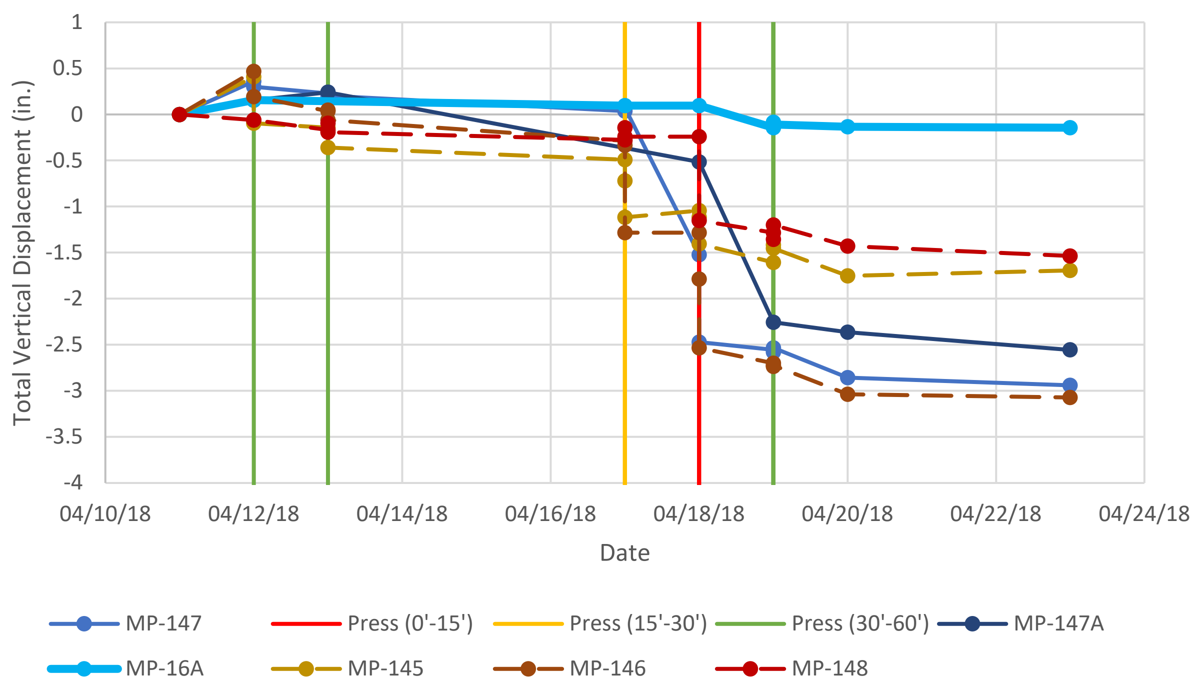

Figure 11: Recorded Vertical Movements during Giken Trial at and near MP-147

- **There are a limited number of Giken machines in the USA and they need to be scheduled in advance.** The silent press is a piece of specialty equipment and is available from only a few equipment suppliers. It is unlikely that more than one piece of equipment could be made available for work in the Canal for more than a short period of time. The equipment typically has to be scheduled several weeks to a few months in advance of the start of sheet pile installation. This order time needs to be accounted for in the project schedule. Additionally, support operations associated with the Giken create logistical constraints within the Canal. TB4 required several barges to support the installation which completely blocked the width of the turning basin. As such, there is limited space available to conduct parallel operations (i.e., multiple bulkhead replacements occurring simultaneously from the water-side) or for any other users of the Canal.

TABLE A1

SUMMARY OF OBSERVATIONS DURING GIKEN TRIAL

Table A1. Summary of Observations during Giken Trial, 3/27/2018 through 4/25/2018

Location	Pile #	Station (ft)	Installation	Target Tip Elev. (ft)	Pile Length (ft)	Top of Pile Elev. (ft)	Actual Pile Tip Elev. (ft)	Installation Date	Time	Installation Method	Notes
Whole Foods 5+25	255	5+82	Pull & Replace	-50	54	4	-50	4/5/2018	1245-1340 (55 min)	Auger+Press	Hard, grinding augering observed at Elev. -45, creating vibrations between 0.025 and 0.05 in/sec.
Whole Foods 5+25	254	5+80	Pull & Replace	-50	54	4	-50	4/5/2018	1245-1340 (55 min)	Auger+Press	
Whole Foods 5+25	253	5+78	Pull & Replace	-50	54	4	-50	4/4/2018	1420-1515 (55 min)	Auger+Press	Hard, grinding augering observed at Elev. -45, creating vibrations between 0.075 and 0.15 in/sec. Auger head was damaged.
Whole Foods 5+25	252	5+76	Pull & Replace	-50	54	4	-50	4/4/2018	1420-1515 (55 min)	Auger+Press	
Whole Foods 5+25	251	5+73	Pull & Replace	-50	54	4	-50	3/27/2018	1510-1630 (80 min)	Press	Hard pressing with lots of rocking observed. Vibrations reached 0.15 in/sec.
Whole Foods 5+25	250	5+71	Pull & Replace	-50	54	4	-50	3/27/2018	1510-1630 (80 min)	Press	
Whole Foods 5+25	249	5+69	Pull & Replace	-50	54	4	-50	3/30/2018	1300-1600 (180 min)	Auger+Press	Hard, grinding augering observed at Elev. -43, creating vibrations between 0.075 and 0.1 in/sec. Likely augered through obstruction.
Whole Foods 5+25	248	5+66	Pull & Replace	-50	51	4	-47	3/30/2018	1300-1600 (180 min)	Auger+Press	
Whole Foods 5+25	247	5+64	Pull & Replace	-50	52	4	-48	4/2/2018	1315-1625 (190 min)	Auger+Press	Hard, grinding augering observed at Elev. -45, creating vibrations between 0.075 and 0.1 in/sec. Debris was caught in the auger. Auger head was heavily damaged.
Whole Foods 5+25	246	5+62	Pull & Replace	-50	53	4	-49	4/2/2018	1315-1625 (190 min)	Auger+Press	
Whole Foods 5+25	245	5+59	Pull & Replace	-50	54	4	-50	4/3/2018	1235-1530 (175 min)	Auger+Press	Hard, grinding augering observed at Elev. -45, creating vibrations between 0.075 and 0.1 in/sec. Likely augered through obstruction.
Whole Foods 5+25	244	5+57	Pull & Replace	-50	54	4	-50	4/3/2018	1235-1530 (175 min)	Auger+Press	
Whole Foods 5+25	243	5+55	Pull & Replace	-50	54	4	-50	4/5/2018	1520-1720 (120 min)	Auger+Press	Slow augering observed at Elev. -36, creating vibrations between 0.025 and 0.05 in/sec. Tire debris was recovered in auger.
Whole Foods 5+25	242	5+53	Pull & Replace	-50	54	4	-50	4/5/2018	1520-1720 (120 min)	Auger+Press	
Whole Foods 5+25	241	5+50	Pull & Replace	-50	54	4	-50	4/6/2018	1025-1125 (60 min)	Press	Hard pressing at elev. -46. Plates to assist grips welded to sheet piles. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.1 in/sec.
Whole Foods 5+25	240	5+48	Pull & Replace	-50	54	4	-50	4/6/2018	1025-1125 (60 min)	Press	
Whole Foods 5+25	239	5+46	Pull & Replace	-50	54	4	-50	4/6/2018	1208-1240 (32 min)	Press	Hard pressing at elev. -47. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.1 in/sec.
Whole Foods 5+25	238	5+43	Pull & Replace	-50	54	4	-50	4/6/2018	1208-1240 (32 min)	Press	

Table A1. Summary of Observations during Giken Trial, 3/27/2018 through 4/25/2018

Location	Pile #	Station (ft)	Installation	Target Tip Elev. (ft)	Pile Length (ft)	Top of Pile Elev. (ft)	Actual Pile Tip Elev. (ft)	Installation Date	Time	Installation Method	Notes
Whole Foods 5+25	237	5+41	Pull & Replace	-50	54	4	-50	4/9/2018	1148-1215 (20 min)	Press	Vibrations <0.05 in/sec during pressing.
Whole Foods 5+25	236	5+39	Pull & Replace	-50	54	4	-50	4/9/2018	1148-1215 (20 min)	Press	
Whole Foods 5+25	235	5+36	Pull & Replace	-50	54	4	-50	4/9/2018	1320-1350 (30 min)	Press	Vibrations <0.05 in/sec during pressing.
Whole Foods 5+25	234	5+34	Pull & Replace	-50	54	4	-50	4/9/2018	1320-1350 (30 min)	Press	
Whole Foods 5+25	233	5+32	Pull & Replace	-50	54	4	-50	4/9/2018	1440-1506 (26 min)	Press	Hard pressing at elev. -51. Vibrations <0.05 in/sec during pressing.
Whole Foods 5+25	232	5+30	Pull & Replace	-50	54	4	-50	4/9/2018	1440-1506 (26 min)	Press	
Whole Foods 5+25	231	5+27	New Sheet Pile	-50	54	4	-50	4/9/2018	1605-1626 (21 min)	Press	Hard pressing at elev. -31 and -48. Vibrations <0.05 in/sec during pressing.
Whole Foods 5+25	230	5+25	New Sheet Pile	-50	54	4	-50	4/9/2018	1605-1626 (21 min)	Press	
Transect	T1	T0+34	New Sheet Pile	-40	46	4	-42	4/10/2018	1625-1641 (16 min)	Press	Hard pressing at elev. -32. Vibrations <0.05 in/sec during pressing.
Transect	T2	T0+37	New Sheet Pile	-40	46	4	-42	4/10/2018	1625-1641 (16 min)	Press	
Transect	T3	T0+39	New Sheet Pile	-40	46	4	-42	4/10/2018	1500-1522 (22min)	Press	Hard pressing at elev. -30. Vibrations <0.05 in/sec during pressing.
Transect	T4	T0+41	New Sheet Pile	-40	46	4	-42	4/10/2018	1500-1522 (22min)	Press	
Transect	T5	T0+44	New Sheet Pile	-40	46	4	-42	4/10/2018	1330-1433 (60min)	Press	Hard pressing at elev. -30 and -35. Stopped for 50 min during driving to weld T7-T10 to waler to increase reaction force. Vibrations <0.05 in/sec during pressing.
Transect	T6	T0+46	New Sheet Pile	-40	46	4	-42	4/10/2018	1330-1433 (60min)	Press	
Transect	T7	T0+48	New Sheet Pile	-40	60	4	-56	4/10/2018	1150-1157 (7min)	Vibratory	Vibrations <0.05 in/sec during vibratory driving.
Transect	T8	T0+51	New Sheet Pile	-40	60	4	-56	4/10/2018	1150-1157 (7min)	Vibratory	
Transect	T9	T0+53	New Sheet Pile	-40	60	4	-56	4/10/2018	1055-1102 (7 min)	Vibratory	Vibrations <0.05 in/sec during vibratory driving.
Transect	T10	T0+55	New Sheet Pile	-40	60	4	-56	4/10/2018	1055-1102 (7 min)	Vibratory	

Table A1. Summary of Observations during Giken Trial, 3/27/2018 through 4/25/2018

Location	Pile #	Station (ft)	Installation	Target Tip Elev. (ft)	Pile Length (ft)	Top of Pile Elev. (ft)	Actual Pile Tip Elev. (ft)	Installation Date	Time	Installation Method	Notes
Transect	T11	T0+57	New Sheet Pile	-40	46	5	-41	4/11/2018	0920-0935 (15 min)	Press	Vibrations <0.05 in/sec during pressing.
Transect	T12	T0+60	New Sheet Pile	-40	46	5	-41	4/11/2018	0920-0935 (15 min)	Press	
Dykes Lumber	1	0+00	New Sheet Pile	-57.5	63	7.5	-55.5	4/18/2018	1330-1348 (18 min)	Press	Hard pressing at elev. -50. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	2	0+02	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1220-1255 (35 min)	Press	Hard pressing at elev. -51. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	3	0+05	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1220-1255 (35 min)	Press	
Dykes Lumber	4	0+07	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1105-1210 (55 min)	Press	Hard pressing at elev. -54. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	5	0+09	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1105-1210 (55 min)	Press	
Dykes Lumber	6	0+11	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1020-1048 (28 min)	Press	Hard pressing at elev. -54. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	7	0+14	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	1020-1048 (28 min)	Press	
Dykes Lumber	8	0+16	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	0925-1014 (49 min)	Press	Hard pressing at elev. -50. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.09 in/sec.
Dykes Lumber	9	0+18	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	0925-1014 (49 min)	Press	
Dykes Lumber	10	0+21	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	0830-0900 (30 min)	Press	Hard pressing at elev. -50. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.09 in/sec.
Dykes Lumber	11	0+23	New Sheet Pile	-57.5	66	8.5	-57.5	4/18/2018	0830-0900 (30 min)	Press	
Dykes Lumber	12	0+25	New Sheet Pile	-57.5	66	8.5	-57.5	4/17/2018	1630-1703 (33 min)	Press	Hard pressing at elev. -49. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	13	0+28	New Sheet Pile	-57.5	66	8.5	-57.5	4/17/2018	1630-1703 (33 min)	Press	
Dykes Lumber	14	0+30	New Sheet Pile	-57.5	66	8.5	-57.5	4/17/2018	1630-1703 (33 min)	Press	Hard pressing at elev. -54. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.2 in/sec. Refusal encounter on SP14 at elev. -54.
Dykes Lumber	15	0+32	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1630-1703 (33 min)	Press	
Dykes Lumber	16	0+34	Pull & Replace	-57.5	62.5	8.5	-54	4/17/2018	1440-1543 (63 min)	Press	Hard pressing at elev. -54. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.2 in/sec. Refusal encountered on SP16 at elev. -54.

Table A1. Summary of Observations during Giken Trial, 3/27/2018 through 4/25/2018

Location	Pile #	Station (ft)	Installation	Target Tip Elev. (ft)	Pile Length (ft)	Top of Pile Elev. (ft)	Actual Pile Tip Elev. (ft)	Installation Date	Time	Installation Method	Notes
Dykes Lumber	17	0+37	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1440-1543 (63 min)	Press	
Dykes Lumber	18	0+39	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1255-1408 (73 min)	Press	Hard pressing at elev. -50. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	19	0+41	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1255-1408 (73 min)	Press	
Dykes Lumber	20	0+44	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1120-1206 (46 min)	Press	Hard pressing at elev. -42 and elev. -55. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	21	0+46	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	1120-1206 (46 min)	Press	
Dykes Lumber	22	0+48	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	0855-1010 (75 min)	Press	Hard pressing at elev. -50. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	23	0+51	Pull & Replace	-57.5	66	8.5	-57.5	4/17/2018	0855-1010 (75 min)	Press	
Dykes Lumber	24	0+53	Pull & Replace	-57.5	66	8.5	-57.5	4/13/2018	1250-1350 (60 min)	Press	Pile was pulled and reset because of issues with verticality. Upon resetting the pile, easier pressing was observed.
Dykes Lumber	25	0+55	Pull & Replace	-57.5	66	8.5	-57.5	4/13/2018	1250-1350 (60 min)	Press	
Dykes Lumber	26	0+57	Pull & Replace	-57.5	66	8.5	-57.5	4/12/2018 - 4/13/2018	1325-1736 (251 min)	Press	Pile was pulled and reset because of issues with verticality. Upon resetting the pile, easier pressing was observed.
Dykes Lumber	27	0+60	Pull & Replace	-57.5	62	8.5	-53.5	4/12/2018 - 4/13/2018	1325-1736 (251 min)	Press	
Dykes Lumber	28	0+62	Pull & Replace	-57.5	63.5	8.5	-55	4/19/2018	1115-1123; 1235-1430; 1555-1655 (183 min)	Press	Pile was first attempted to overlap in front of the original piles. Original piles were too out of vertical alignment, so the original pile was pulled, and the replacement pile re-driven. Hard pressing at elev. -54. vibrations <0.05 in/sec during pressing.
Dykes Lumber	29	0+64	Pull & Replace	-57.5	66	8.5	-57.5	4/19/2018	1115-1123; 1235-1430; 1555-1655 (183 min)	Press	
Dykes Lumber	30	0+67	Pull & Replace	-57.5	46	8.5	-37.5	4/19/2018	1730-1800 (30 min)	Press	Hard Pressing at elev. -45. Vibrations <0.05 in/sec during pressing.
Dykes Lumber	31B	0+69	Extra Overlap Pile	-57.5	46	8.5	-37.5	4/19/2018	1730-1800 (30 min)	Press	
Whole Foods 6+25	281	6+43	Pull & Replace	-58	65	4	-61	4/23/2018	1058-1455 (237 min)	Press	Hard Pressing at elev. -38 to elev. -52. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.15 in/s.
Whole Foods 6+25	280	6+41	Pull & Replace	-58	65	4	-61	4/23/2018	1058-1455 (237 min)	Press	

Table A1. Summary of Observations during Giken Trial, 3/27/2018 through 4/25/2018

Location	Pile #	Station (ft)	Installation	Target Tip Elev. (ft)	Pile Length (ft)	Top of Pile Elev. (ft)	Actual Pile Tip Elev. (ft)	Installation Date	Time	Installation Method	Notes
Whole Foods 6+25	279	6+44	Pull & Replace	-58	65	4	-61	4/24/2018	0830-0945 (75 min)	Press	Hard Pressing at elev. -41. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.15 in/s.
Whole Foods 6+25	278	6+42	Pull & Replace	-58	65	4	-61	4/24/2018	0830-0945 (75 min)	Press	
Whole Foods 6+25	277	6+45	Pull & Replace	-58	65	4	-61	4/24/2018	1300-1450 (110 min)	Press	Hard Pressing at elev. -42. Vibrations <0.05 in/sec during pressing. Grip slips caused vibration spikes of 0.15 in/s.
Whole Foods 6+25	276	6+43	Pull & Replace	-58	65	4	-61	4/24/2018	1300-1450 (110 min)	Press	
Whole Foods 6+25	275	6+46	Pull & Replace	-58	65	4	-61	4/25/2018	0845-1015 (90 min)	Press	Hard Pressing at elev. -41. Vibrations <0.05 in/sec during pressing.
Whole Foods 6+25	274	6+44	Pull & Replace	-58	53	4	-49	4/25/2018	Not replaced (pulling attempted for 90 min)	N/A	Original pile could not be removed. Pulled with Giken at maximum 130 ton force, and did not move. Caused reaction piles that Giken was mounted on to sink a few inches. Decision was made not to remove/replace this pile.

Notes
1) All elevations are in NAVD88.
2) Highlighted cells represent piles that did not achieve target tip.

ATTACHMENT C

DEBRIS FIGURES

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Legend

Target Size (Maximum of Length or Width)

- Less than 2 Feet
- 2 to 5 Feet
- 5 to 10 Feet
- Greater than 10 Feet
- Debris Field[2,3,5]
- Bulkhead Failed[4]
- Street End/Bridge[4]

Notes:
1. Debris observation data was collected by SeaVision Underwater Solutions in January 2015 with the exception of the 4th St. Turning Basin (TB4) which was collected in December 2016 after commencement of debris removal activities as part of the TB4 Debris Removal Pilot Study.
2. Debris fields are defined by SeaVision as large swaths of Canal bottom that are filled with debris targets, some of which are noticeable in the imagery but not practical to target individually due to the sheer volume of targets. Green labels indicate the % of debris coverage for each debris field.
3. Debris fields are known to have large number of indiscernible targets and encountering debris during sheet pile installation or dredging is expected.
4. Failed bulkheads and street ends are areas with a high likelihood of debris being present.
5. The targets and debris field shown are near surface debris. Debris can be expected randomly throughout the soft sediment column.

200 100 0 200 Feet

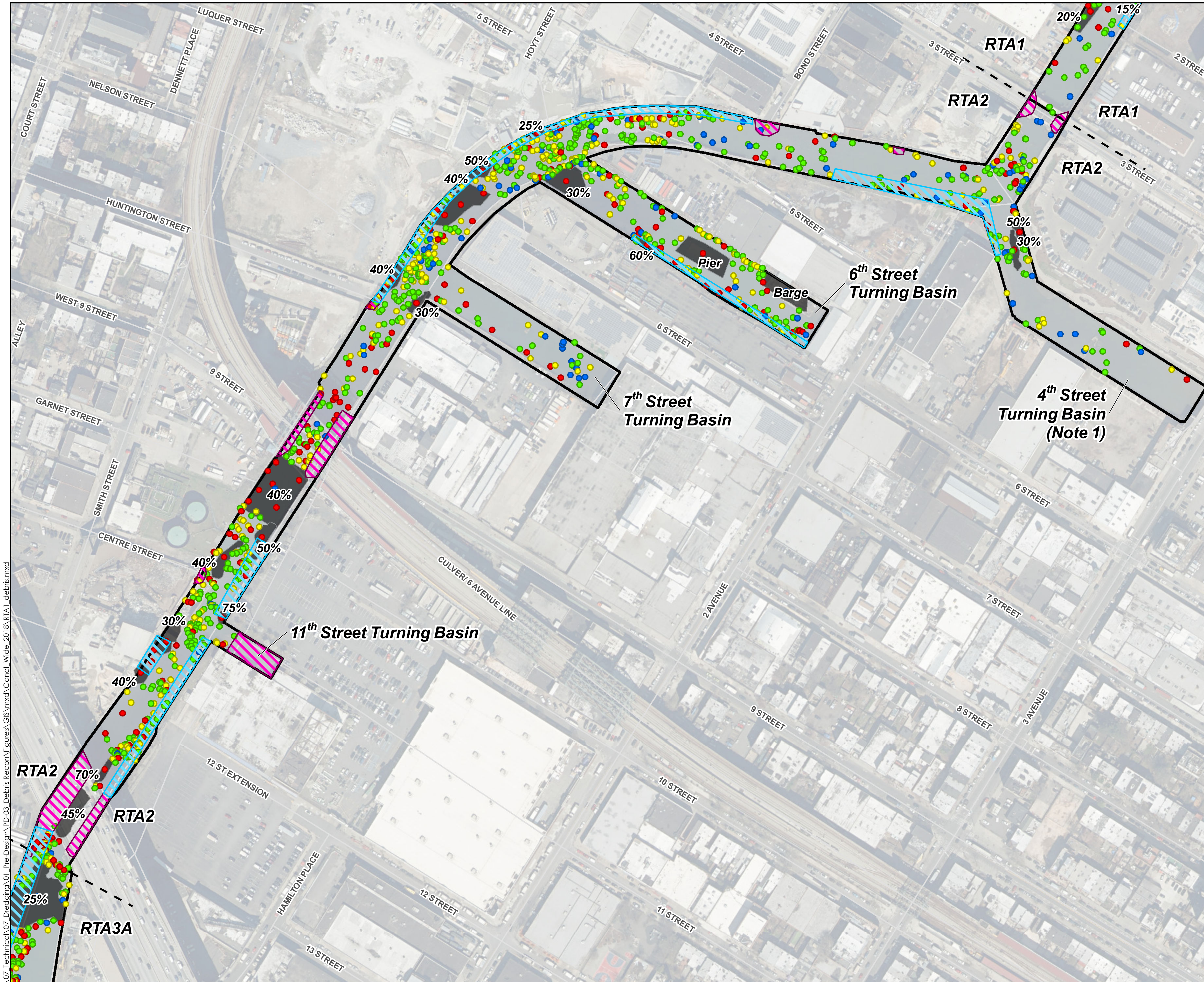
RTA1 Debris

Gowanus Canal, Brooklyn, NY

Gowanus Canal Remedial Design Group | Geosyntec consultants | Beech and Bonaparte engineering p.c. an affiliate of Geosyntec Consultants

Figure 1

Ewing, NJ | June 2018



Legend

Target Size (Maximum of Length or Width)

- Less than 2 Feet
- 2 to 5 Feet
- 5 to 10 Feet
- Greater than 10 Feet
- Debris Field[2,3,5]
- Bulkhead Failed[4]
- Street End/Bridge[4]

Notes:
1. Debris observation data was collected by SeaVision Underwater Solutions in January 2015 with the exception of the 4th St. Turning Basin (TB4) which was collected in December 2016 after commencement of debris removal activities as part of the TB4 Debris Removal Pilot Study.
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3. Debris fields are known to have large number of indiscernible targets and encountering debris during sheet pile installation or dredging is expected.
4. Failed bulkheads and street ends are areas with a high likelihood of debris being present.
5. The targets and debris field shown are near surface debris. Debris can be expected randomly throughout the soft sediment column.

200 100 0 200 Feet

RTA2 Debris

Gowanus Canal, Brooklyn, NY

Gowanus Canal Remedial Design Group | Geosyntec consultants | Beech and Bonaparte engineering p.c. an affiliate of Geosyntec Consultants

Figure **2**

Ewing, NJ | June 2018

N

Legend

Target Size (Maximum of Length or Width)

- Less than 2 Feet
- 2 to 5 Feet
- 5 to 10 Feet
- Greater than 10 Feet
- Debris Field[2,3,5]
- Bulkhead Failed[4]
- Street End/Bridge[4]

Notes:

1. Debris observation data was collected by SeaVision Underwater Solutions in January 2015 with the exception of the 4th St. Turning Basin (TB4) which was collected in December 2016 after commencement of debris removal activities as part of the TB4 Debris Removal Pilot Study.
2. Debris fields are defined by SeaVision as large swaths of Canal bottom that are filled with debris targets, some of which are noticeable in the imagery but not practical to target individually due to the sheer volume of targets. Green labels indicate the % of debris coverage for each debris field.
3. Debris fields are known to have large number of indiscernible targets and encountering debris duing sheet pile installation or dredging is expected.
4. Failed bulkheads and street ends are areas with a high likelihood of debris being present.
5. The targets and debris field shown are near surface debris. Debris can be expected randomly throughout the soft sediment column.

200 100 0 200 Feet

RTA3 Debris

Gowanus Canal, Brooklyn, NY

Gowanus Canal Remedial Design Group

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Figure 3

Ewing, NJ | June 2018

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