Pile Wrap Evaluation Study

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Introduction

A two-year study in New York City's East River was performed to evaluate the effectiveness of various marine timber pile wrapping systems in protecting timber elements from marine borer attack. This paper will provide an overview of that study, as well as discuss the results of the periodic inspections and dissolved oxygen testing conducted, including methodology and procedures. While it is not the intent of this paper to endorse or reject the product of a particular manufacturer, some advantages and disadvantages of the various marine timber pile wrapping systems will be presented.

Background

Once considered one of the most polluted waterways in the United States, New York Harbor has, in the last 30 years, become significantly less polluted. This is attributable to the Clean Water Act of 1972, which placed strict limits on allowable pollutant levels for industry effluents and waste products. One unintended and unfortunate consequence of the improvement in water quality was the resurgence of marine borers and their destructive consumption of the subaqueous timber elements upon which the vast majority of New York's waterfront structures are built. The effect of that consumption is a reduction in the structural capacity of timber support structures caused by the loss of cross-sectional area of individual structural elements.

Within New York Harbor there are two species of marine borers that pose a serious threat to timber structures: crustaceans (wood gribbles) and mollusks (shipworms). The most common crustacean found in the Harbor *is Limnoria Tripunctata*, a free swimming organism capable of moving in and around timber. On a timber pile, for example, limnoria attack from the outside, burrowing parallel to the grain with frequent openings to the water for circulation. While the burrows are not very deep, if left unchecked they continue to consume timber, resulting in a pile with significant cross-sectional loss. Because the attack occurs on the surface of a pile, its presence is fairly easy to detect, and measures can be taken to prevent further damage.

The most common mollusk found in New York Harbor is *Teredo Navalis*. Teredo begin life as water-borne larvae with a gestation period of three weeks, and are distributed by currents. Once the larva finds a section of timber, it will burrow into it and metamorphose into a shipworm. It then continues to burrow parallel to the grain of the wood, forming tunnels that never bisect other teredo tunnels or the outer surface of the timber. Because they burrow inside the timber, teredo activity is difficult to detect in a visual inspection, so a pile may appear to be in satisfactory condition when it is not. Consequently, steps that may be taken to prevent further damage are delayed.

To prevent further damage to timber piles suffering damage from marine borer activity, various barrier remediation techniques have been designed and installed on timber piles. These barriers were based on the assumption that if a pile is encapsulated with an impervious membrane, such as a reinforced flexible plastic wrap, water would be trapped in the annular space formed between the pile and the newly installed wrap. Since, theoretically, water exchange would no longer occur, the result would be the reduction of dissolved oxygen in the ostensibly stagnant water within the annulus, to levels that would no longer be able to sustain borer activity. Many timber piles in New York Harbor were thus encapsulated with reinforced flexible plastic wraps. Unfortunately, over the ensuing years, several inspections conducted throughout the Harbor indicated that a high percentage of these pile wraps were ineffective. It was in response to these findings that this study was initiated in the Fall of 2001.

Site Location

The New York City Economic Development Corporation (NYCEDC) provided Piers 13 and 14, located along the East River, as the testing site. Built circa 1930, each pier is approximately 600 ft long and 80 ft wide. These piers were rehabilitated in 1994, and a majority of the timber piles supporting them were wrapped in an attempt to stop the deterioration that was occurring due to marine borer activity. Years later, dissolved oxygen (DO) testing on these piles revealed that the majority of these wraps appeared to be ineffectual. In November of 2000, a routine inspection of these piers was performed that included the removal of several wraps in an attempt to determine whether deterioration of the timber due to marine borer activity had progressed. Comparing minimum remaining diameter measurements with those recorded in a 1992 inspection revealed that cross-sectional reduction of these piles had continued at a rate of approximately 0.8 cm to 1.3 cm per year.

Methodology

In an attempt to determine how effective barrier remediation techniques are in preventing marine borer activity, various manufacturers were contacted and asked to donate materials for the study. Nine different pile wrap systems from four different manufacturers were donated. The wrap systems included four positive closure wrap systems and five overlap closure wrap systems. The wraps were constructed of Ethylene Propylene Diene Terpolymer (EPDM), High Density Polyethylene (HDPE), or Polyvinyl Chloride (PVC) of varying thicknesses. For the purposes of this study, these wrap systems will be referred to as Wraps 1 through 9 (Table 1).

Table 1
Pile Wrap Types

Wrap #	Wrap Type	Wrap #	Wrap Type
1	Positive Closure (EPDM)	6	Double-layer (EPDM w/ protective outer wrap)
2	Positive Closure (PVC)	7	Double-layer (PVC w/ HDPE outer wrap)
3	Positive Closure (EPDM)	8	Double-layer (EPDM w/ petrolatum-sat. tape # 1)
4	Positive Closure (Flanges)	9	Double-layer (PVC w/ petrolatum-sat. tape # 2)
5	Single-layer (EPDM w/ vertical adherent)		

The positive closure wrap systems typically have a flexible polyether-type polyurethane foam attached on the inside, around the top and bottom. One type of positive closure wrap has two wooden pole pieces attached vertically along each side of the wrap (Wraps 1-3). These two pole pieces are held together and, with a special ratchet, twisted clockwise until the wrap is secure. Stainless steel nails are then driven into the pile through the two pole pieces, as per the manufacturer's specifications, and stainless steel bands are installed around the top and bottom of the wrap.

A second type of positive closure wrap is one with pre-drilled square plastic flanges attached vertically along the sides of the wrap (Wrap 4). Once circumferential measurements of the pile are taken, the wrap is cut to size, fitted on the pile, and the flanges are brought together and attached with lag bolts, using pneumatic tools. Stainless steel bands are then installed at the top and bottom of the wrap. In effect, with either of these wrap systems, there is no vertical seam through which water exchange can occur.

The overlap closure wrap systems (Wraps 5-9) typically have a flexible polyether-type polyurethane foam attached on the inside around the top and bottom. On some wraps, this foam is also attached on the inside along one of the vertical seams. When this wrap system is installed, one side of the wrap is nailed to the pile from top to bottom, as per the manufacturer's specifications, and the other end of the wrap is pulled around the pile, overlapping the vertically nailed section. This end is then similarly nailed along its full vertical length. As this vertical seam is not water-tight, the possibility of having an exchange of water does exist. Some of these overlap closure wraps have two layers, an inner layer and a significantly thicker (up to 4.1 mm) outer layer, made of HDPE, which functions as either abrasion protection (Wrap 6), or as a second layer of protection against marine borer activity (Wrap 7). Additionally, some of the overlap closure wrap systems were installed over piles that had a base layer tape coating (Wraps 8 and 9). This layer essentially consists of a high tensile strength synthetic fabric saturated with a specially formulated petrolatum-based compound that has water displacing agents and wide spectrum biocides. In this study, two different petrolatum-based tapes were used.

All of these wrap systems were installed on timber piles located at the inshore, midshore and offshore sections of the piers. These locations were selected so that each wrap could be evaluated under typical conditions.

Before installation could take place, the existing wraps were completely removed, and the marine growth was cleaned off each pile. This was followed by the installation of three untreated pine furring test strips along the full length of the pile to be encapsulated. These strips would serve to indicate, at the end of the study, whether or not marine borer activity was taking place beneath each wrap. Once these strips were attached, the donated wraps were installed at the pre-determined locations under the supervision of representatives from each of the manufacturers. All wraps were installed to at least 0.6 m below the existing mudline, which was eventually backfilled. In total, thirty wraps were installed on Piers 13 and 14.

<u>*DO Testing Procedure*</u> - The purpose of taking DO readings was to determine if the dissolved oxygen content of the stagnant water trapped in the annular space between the timber pile and the newly installed wrap was below 1.50 mg/l. This is the generally accepted number below which marine borers cannot exist due to lack of oxygen. Though there has been some debate as to whether this number is accurate, for the purposes of this study, readings of 1.50 mg/l or less were considered to be "passing". In addition to the Dissolved Oxygen Meter (YSI 95 DO meter) used for analyzing the samples, 60cc Syringes, 12 gauge needles with side inlet, and 10 cm stainless steel nails with rubber grommets were utilized.

Prior to taking DO readings, the meter was calibrated using the manufacturer's calibration procedures. For this study, it was assumed that the salinity of the water was 25 ppm, and the elevation was at sea-level. Samples were obtained in the following manner: a diver would approach a pile with a syringe, plunger fully depressed, with a safety cap over the needle. The diver would then pierce the wrap and slowly extract a sample of water from the annular space between the pile and wrap. Once the maximum obtainable sample volume was extracted, the needle was carefully withdrawn and the safety cap replaced. One stainless steel nail was then driven through the needle hole with a 3lb hammer. Care was taken to ensure that the nail was driven fully into the timber so that the rubber grommet would seal the hole. The sample was handed to the tender, who was standing by with the DO meter. The plunger was then removed from the syringe, the probe inserted, and the sample gently stirred until the reading stabilized. The DO reading, as well as the temperature of the sample and the time of day, was recorded. Samples were typically taken 0.3 m above the mudline and 0.3 m below mean low water (MLW). Samples of the ambient water were taken at the same locations and similarly recorded.

There were six piles that had a petrolatum-saturated tape beneath an outer wrap. Because this tape essentially covered every contour of a pile, there was no annular space and, consequently, DO testing was not conducted on these piles. They were, however, visually inspected along with the other wrap types, and the recovered furring strips were assessed at the end of the study.

Installation Observations

<u>*Positive Closure Wraps*</u> - Each wrap system installed has its advantages and disadvantages. The biggest advantage of this wrap system is that it can be installed very tightly, minimizing the amount of space between the wrap and the pile itself, thereby limiting the amount of water exchange that can take place. The absence of an

exposed vertical seam further limits the chances of any water exchange occurring, ensuring that the stagnant water in the annulus remains entrapped. Another advantage is that installation is a one step process. There is only one layer of wrap to install. Wrap 4 has a unique advantage in that it can be unwrapped by removing the lag bolts, and then reinstalled. This allows access to the timber pile beneath, which can be assessed for further deterioration.

One of the observations noted during wrap installation is that, to minimize the chances of puncturing a wrap, care must be taken to identify and break off any sharp protrusions extending from the pile prior to installation. This is particularly important when installing a positive closure wrap because of the ease with which it can be tightened. It was also observed that the wood pole pieces, while not fragile, can be broken if not handled carefully. A slight disadvantage of this wrap system is that special tools are required for installation; a ratchet for Wraps 1-3, and pneumatic tools for Wrap 4. For Wraps 1-3, space to attach and effectively turn a ratchet must be adequate, making it more difficult to install under some circumstances. Because of this, more care is required in deciding which side of a pile to place the vertical closure seam, especially if two sections of wrap must be overlapped, since the vertical closure seam on the second wrap must be placed 90 degrees from the vertical seam of the wrap above or below.

Of the two positive closure wrap systems evaluated in this study, the type with wooden pole pieces was easier to install since pneumatic tools were not required, and there was less of a need to obtain as many accurate cross-sectional measurements on a given pile.

Overlap Closure Wrap - The overlap wrap systems are relatively easy to install. Since several different types were used in this study, the wraps will be separated and discussed as follows; those consisting of a single layer (Wrap 5), those consisting of two layers (Wraps 6 and 7), and those with a base layer of petrolatum-saturated tape covered with a single layer (Wraps 8 and 9). The main advantage of all these wraps is that no specialized tools, other than the basics (hammer, banding tool and in some instances, ratchet straps), are required for installation.

Single-Layer Wrap - The single-layer wrap systems tested have the advantage of being a one step process. This type of wrap may or may not have an adherent running vertically along one side of the wrap, making it easier to seal the overlapping section against itself. A disadvantage is that it can not be installed as tightly as a positive closure wrap. There will typically be areas where the wrap is loose, so that pockets containing water may exist. However, if the wrap does not allow for the exchange of water with the outside environment, this should not matter.

Another concern involves the vertical seam, particularly on the wrap with no adherent (Wrap 9). Even with nails spaced at 15 cm intervals along the vertical seam, there is a greater likelihood that an exchange of water could occur with this wrap system as compared to one of the positive closure wraps.

Double-Layer Wrap - The double-layer wrap systems installed typically consist of an inner wrap made of 1.5 mm thick PVC or EPDM, and an outer wrap made of High Density Polyethylene (HDPE) up to 4.1 mm in thickness, both of which are installed in the same way as the single-layer wrap. In this study, one of the double-layer wrap systems installed is essentially a one layer-wrap with a thick outer wrap installed solely as abrasion protection (Wrap 6). This outer wrap is typically installed in the tidal zone only. Both layers are easy to install and require only basic tools.

The outer cover of Wrap 7 is intended to function as a second layer of protection against marine borer activity. This outer wrap has foam seals which adhere to the inside along the vertical seam, and along the top and bottom. Because this outer wrap is intended to protect against marine borer activity, it must be installed as tightly as possible in order to conform to the contours of a deteriorated pile. This can be more difficult to accomplish because of its thickness.

The main disadvantage with both of these wraps is the fact that installation is now a two step process, and as such, requires more labor. Installing this type of wrap could thus be limited to piles that are most likely to suffer from abrasion damage, such as piles located along the perimeter of a pier.

Petrolatum-Saturated Tape - There were two wrap systems tested that have a base layer of petrolatum-saturated tape underneath a single-layer wrap composed of either EPDM or PVC. Both types of petrolatum-saturated tapes are applied in the same way. Starting from the bottom of the exposed pile and holding the end firmly against the pile, the tape is unrolled. Keeping the roll close to the pile and applying sufficient tension to provide continuous adhesion, the pile is wrapped to the top with a 2.5 cm minimum overlap. Once this step is complete, the one-layer wrap is installed in the manner previously described.

The petrolatum-saturated tapes differed in color, but were similar in consistency. Both were also extremely easy to apply and adhered very well. The advantage of using this petrolatum-saturated tape is that all of the contours of a deteriorated pile can be covered. There is no annular space between the tape and pile so that, unless water is able to penetrate the tape itself, oxygen levels will be reduced to levels that are unsuitable for sustaining marine borer activity. On top of the base layer of tape, a single-layer wrap is installed. So, essentially, there are two layers of protection and no annular space between the wrap and pile. The disadvantage is the fact that it is a two step process which requires more labor. It is also unknown if the petrolatum-based tape is completely non-porous, or whether it will deteriorate and become ineffectual over a prolonged period of time if exposed to the outside environment.

Evaluation

Following the wrap installation, the effectiveness of each wrap system was evaluated in two ways. First, quarterly inspections were performed over the two year duration of the study. These inspections consisted of visual observations of each wrap to determine how well a particular wrap system performed in its environment. In addition, the mudline was inspected for signs of scour, particularly because of the high ferry traffic adjacent to both piers. Any observed deficiencies were noted and monitored in subsequent inspections.

Second, at the conclusion of the study, each wrap was removed and all test strips were recovered and inspected for evidence of marine borer activity. This would indicate whether or not a particular wrap was preventing marine borer intrusion.

The other aspect of this study involved an attempt to determine the reliability of DO testing as an indicator of wrap efficiency. This method of testing consists of extracting a sample of the water from the annular space between the wrap and the timber pile, and measuring the DO content of that sample. If the DO level recorded is below 1.50 mg/l, then the wrap from which the sample was extracted is deemed effective. The DO testing was performed on the same days that the visual observations were performed at each wrap.

Results

The results of this study are broken down into three parts. First, the results of the visual inspections are presented. The second part presents the results of the DO testing performed over the course of the study. Third, the results of the DO testing are compared to the observations of the test strips recovered from beneath each wrap. This comparison was made in an effort to determine if DO testing can be used to accurately determine whether a wrap is effective in preventing marine borer activity.

Visual Inspection - Over the course of the study, all of the wraps held up well, whether they were made of EPDM, HDPE, or PVC. None of the wraps installed suffered any notable damage.

Of the 30 wraps installed, there were two locations where loose nails were observed. Both occurred with Wrap 9 in a 0.6 m high area within the tidal zone. It is possible that, due to wave action, water worked its way between the nails and the pile. It could also have been due to floating debris. There was no exposed petrolatum tape at this elevation.

There were three wraps from which a stainless steel band fell off due to corrosion at either the mudline or at the overlap. These were observed during the final inspection, but were intact during previous inspections. The failed bands were observed at Wrap 2, at the midshore and offshore locations, and Wrap 3 at the inshore location.

One other observation of note occurred once the wraps were removed. This observation involved Wraps 8 and 9. While the petrolatum-saturated tapes used with both of these wraps were similar in consistency when applied, once the wraps were removed, the petrolatum-based tape used with Wrap 9 had changed, taking on an almost wax-like consistency, in contrast to the tape used with Wrap 8, which did not appear to change in any way. The petrolatum-saturated tape underneath this wrap appeared as if it was recently installed, even though it was in place for two years. This may be due to the seal achieved along the vertical seam due to the adherent. It is likely that less water gets through this vertical seam than through a vertical seam that is simply nailed at regular intervals.

Although all thirty piles were wrapped to at least 0.6 m below the mudline, thirteen piles were subject to the effects of scour and accretion. For example, on one visit the timber below the wrap was exposed and on a subsequent visit, it was not. At eight of those thirteen locations, the timber below the wrap was exposed for a majority of the study, and of those eight, seven were located along the perimeter of the pier. Five of those seven were located at the midshore sections of the piers.

Results of DO Testing vs. Test Strip Results – At the end of the study, an average was calculated of the number of times a sample had a DO reading of 1.50 mg/l or less. These were considered as having received a "passing grade" and the results, separated by the elevation and location on the pier at which the sample was recovered, are summarized in Table 2. This table also includes the results of the inspection of the test strips recovered from each pile, which were considered to have passed or failed based on whether or not marine borer activity was evident. If a test strip failed, the elevation at which it failed is noted.

While none of the wraps passed 100% of the time, Wraps 4 and 7 failed a majority of the time at all locations and elevations. The failures on Wrap 7 may be due to the difficulty in obtaining a sample from this wrap system. It is hard to be certain that both layers are being penetrated when attempting to acquire a sample. For instance, if a DO reading taken on this wrap failed, it could not be concluded with any degree of certainty that both layers were penetrated and that the reading was an actual measurement of the level of dissolved oxygen in the water entrapped between the inner wrap and the timber pile. It is possible that the sample was that of the water trapped between the two layers of wrap, which may serve to indicate that the outer wrap was failing.

While it appears clear that the positive closure wraps, in general, passed more often than the overlap closure wraps, none passed more than 80% of the time. The other figure that stands out is that none of the wraps passed more than 50% of the time at MLW at any location.

Table 2
Dissolved Oxygen (DO) Test Results

Wrap #	Wrap Type	Location	Elevation	% Passing DO Test	Test Strip Result
1	Positive Closure (EPDM)	Inshore	Mudline MLW	75 25	**PASS**
		Midshore	Mudline MLW	57 29	**FAIL @ Mid**
		Offshore	Mudline MLW	71 43	**PASS**
2	Positive Closure (PVC)	Inshore	Mudline MLW	71 43	**PASS**
		Midshore	Mudline MLW	57 43	**FAIL @ Mid**
		Offshore	Mudline MLW	33 50	**PASS**
3	Positive Closure (EPDM)	Inshore	Mudline MLW	67 33	**PASS**
		Midshore	Mudline MLW	67 50	**PASS**
		Offshore	Mudline MLW	83 17	**PASS**

Wrap #	Wrap Type	Location	Elevation	% Passing DO Test	Test Strip Result
4	Positive Closure (Flanges)	Inshore	Mudline MLW	- 0	**PASS**
		Midshore	Mudline MLW	- 29	**PASS**
		Offshore	Mudline MLW	33 43	**PASS**
5	Single-layer (EPDM w/vertical adherent)	Inshore	Mudline MLW	71 29	**FAIL @ Mid**
		Midshore	Mudline MLW	60 0	**FAIL @ Mid**
		Offshore	Mudline MLW	43 29	**PASS**
6	Double-layer (EPDM w/protection outer wrap)	Inshore	Mudline MLW	25 0	**PASS**
		Midshore	Mudline MLW	80 40	**FAIL @ Mid**
		Offshore	Mudline MLW	71 29	**FAIL @ ML**
7	Double-layer (PVC w/HDPE outer wrap)	Inshore	Mudline MLW	0 0	**N/A**
		Midshore	Mudline MLW	25 13	**FAIL @ ML**
		Offshore	Mudline MLW	29 14	**PASS**
8	Double-layer (EPDM w/petrolatum-saturated tape # 1)	Inshore	Mudline MLW	N/A N/A	**PASS**
		Midshore	Mudline MLW	N/A N/A	**PASS**
		Offshore	Mudline MLW	N/A N/A	**PASS**
9	Double-layer (PVC w/petrolatum-saturated tape # 2)	Inshore	Mudline MLW	N/A N/A	**PASS**
		Midshore	Mudline MLW	N/A N/A	**PASS**
		Offshore	Mudline MLW	N/A N/A	**FAIL @ Mid**

When looking for a correlation between the results of the DO tests and the condition of the test strips, Table 2 shows several inconsistencies. For example, Wrap 6 at the inshore location failed to pass 75% of the time at the mudline and 100% of the time at MLW, yet when the timber strips were recovered and inspected, there were no signs of marine borer activity. Another example is Wrap 4, which failed to pass a majority of the time at both elevations, regardless of location on the pier, yet none of the timber test strips had any indication of marine borer activity. Only Wraps 3, 4, and 8 had test strips with no signs of marine borer activity at any location.

On occasion, the correlation between the DO testing and test strip observations were clear. This was evident, for example, with Wrap 5 at the inshore location. This wrap failed DO tests 71% of the time at MLW, but passed 71% of the time at the mudline. All test strips collected at this location had limnoria at MLW only.

Conclusions and Suggestions

There were several interesting observations that were evident by the end of this two year study. The first has to do with the scour observed. Though the industry standard is to install wraps 0.6 meters below the mudline, it may have to be adjusted based on location. For instance, in areas that are subject to a high volume of ferry traffic, wraps installed on perimeter piles should extend more than 0.6 meters below natural bottom. This scour problem also helps underscore the importance of sealing the bottom of a wrap. During installation, some wraps do not get sealed at the bottom, the thought being that since they are buried below the mud, it is not necessary. This is clearly not the case. To ensure that this does not occur, quality control inspections should be conducted during installation.

It is also important to do routine inspections on every installed wrap. As was the case in this study, the bands that are needed to ensure a good seal can corrode and fall off. This can cause an effectively functioning wrap to fail. In this study, the wraps from which two of the three bands fell off did not appear to have any borer activity, based on observation of the test strips. The test strips recovered from the third pile, Wrap 2 at the midshore location, had limnoria at the mid elevation, but it is doubtful that this was due to the missing band as it only came off sometime in the last three months of the study.

This study also set out to determine whether or not DO testing can be reliably used to determine if a wrap is effectively preventing marine borer activity. This was assessed by comparing the results of the DO tests with the observed results of the untreated pine furring strips recovered at the end of the study. Based on these comparisons, it does not appear that DO testing is a reliable means to determine whether or not marine borer activity is taking place. This is based on the fact that several of the recovered test strips had no evidence of marine borer activity, yet failed the DO testing a majority of the time.

Based on all of the information gathered in this study, the positive closure wrap systems, and the wrap systems with a petrolatum-saturated base layer, are the most effective wrap systems in preventing marine borer activity. Of the eighteen locations at which these wrap systems were installed, only the test strips recovered from three of those locations had limnoria infestation. When compared to the fact that the recovered test strips from four of the six locations at which overlap closure wraps were installed had limnoria infestation, it is clear, based on this study, that the positive closure wrap systems, and the wrap systems with a petrolatum-saturated base layer, are more effective in preventing marine borer activity.

Of the two types of positive-closure wraps tested, the system using the wooden pole pieces is the best wrap system to use on piles that are already deteriorated. This is based mainly on the ease of installation. Of the two wrap systems that use a petrolatum-saturated tape as a base layer, Wrap 8 performed best. This is based mainly on the observed condition of the timber test strips recovered from beneath these wraps. Not only was the absence of marine borer activity clear but, as previously mentioned, they appeared to have been recently installed. Overall, this wrap is the one that performed the best over the course of the study.

It might be advantageous to combine the two wrap systems that performed best. Applying the petrolatum-saturated base tape used with Wrap 8, underneath a positive-closure wrap would seem to afford a pile the best protection possible as far as wraps are concerned.