CORROSION PROBE, INC.

THE COMPLETE ENGINEERING APPROACH - FROM DETECTION TO CORRECTION

Coating Failure Analysis Report

for

Sheet Pilings

at

De Laval Project
in
Poughkeepsie, NY

Prepared for:

Ocean and Coastal Consultants

Prepared by:

Corrosion Probe, Inc.

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1.0 <u>Introduction</u>

On November 12, 2009 Corrosion Probe, Inc. (CPI) performed an onsite coating failure investigation on in-place sheet pilings along the east side of the Hudson River in Poughkeepsie, NY. The piles were prepared and shop coated and installed between June and November 2008. In August 2009 localized coating failure was observed by Ocean and Coastal Consultants (OCC) during a follow-up inspection. In part, OCC reported widespread damage throughout the waterward face of the pilings , top of sheet "coating damage caused by vibratory hammer grab points", "long striations possibly caused by false work during installation and/or abrasion damage caused by placement of rip rap", "widespread map cracking and long hairline cracks" ("typically contained to above the tidal zone").

The coating specification (see Appendix to this report) required Near-White Blast Cleaning in accordance with SSPC-SP 10 with a 1.5 to 2.5 mil surface profile. The specified coating system was Bar-Rust 235 by Devoe Coatings. However, Macropoxy 646 by Sherwin-Williams was approved as a substitution.

Both the land and waterward side of sheet piles in Zone 1 and Zone 3 were examined. Due to limited time, the majority of the field investigation focused on Zone 1. The Zone 1 bulkhead is approximately 334 feet long and the Zone 3 bulkhead is approximately 658 feet long (not including the returns).

This report presents the results of CPI's one day onsite visit including visual findings, adhesion, dry film thickness (DFT) measurements, solvent rub testing, annotated photographs, a technical discussion, and conclusions as to the cause(s) of failure and recommendations for corrective action. Observations and testing were performed from the land side and water side. The water side was accessed from a boat during low tide.

2.0 Field Findings and Test Data

An initial observation common to both sides of the piles was that there are numerous existing touch-up coating areas. CPI remains uncertain regarding the type of failures (e.g. mechanical damage, cracking) which necessitated these field repairs, but assume that touch-up coating was performed because of a variety of coating related failures or defects. See Photo 1.

Coating cracks were of primary concern to OCC and that was the main focus during our investigation. Cracking was not exclusive to web to flange locations in the sheet piles; however, the vast majority of the cracks were observed at those areas. Dry film thickness measurements were obtained in close proximity to cracked and non-cracked areas using non-destructive (dry film thickness gages) and destructive methods following sample removal and direct measurement via a micrometer. The later method provided a view of the substrate for observation relative to the degree of cleanliness and surface profile (roughness) provided during original shop surface preparation.

The specified degree of cleanliness was SSPC SP-10 Near –White Blast Cleaning with a surface profile of 1.5 – 2.5 mils. At all locations observed the degree of cleanliness appeared acceptable. Surface profile measurements, accomplished by comparison between respective sheet pile steel surface conditions and a (replica) surface profile comparator disc, were typically between 2.0 to 3.0 mils. However, steel surfaces had a rounded, peened texture as opposed to a sharp, angular (sandpaper-like) texture. Note that paragraph 3.1 A. of the protective coating specification Section 09905 states, in part, the following relative to surface preparation and, specifically, regarding surface profile: "Blast profile on steel shall be 1.5 to 2.5 mils in depth and be of a sharp, jagged nature as opposed to a peen pattern from shotblasting." Recyclable (rounded) steel shot is typically used in shop surface preparation operations in combination with more angular abrasives (e.g. coal or furnace slag). It would appear that the reuse of steel shot without angular abrasives or the lack of sufficient cutting action resulted in the peened appearance of the substrate. See Photo 2.

Sample acquisition for the purposes of possible material property laboratory testing, coating thickness measurement and substrate examination revealed that the coating was very brittle when compared to other cured samples of Macropoxy 646 examined by CPI on other past coating projects. None of the coating samples acquired exceeded .75 sq. in. and, for the most part, were ½" to ¼"or smaller and often powdery. Samples were readily chipped as opposed to peeled-off. It was difficult to get large samples without first applying tape to the areas and chipping with the tape acting as a backing to retain the sample.

As a measure of extent of coating cure, solvent rub testing was performed in accordance with ASTM D 5402, Standard Practice for Assessing Solvent Resistance of Organic Coatings Using Solvent Rubs. Testing at representative areas, using MEK on white cotton cloths, produced black residue. Other than some marginal dulling, the coating did not soften or show other signs of degradation. This indicates the full cure of the coating was obtained for the areas tested. This is a practical field test to determine extent of cure. More conclusive laboratory testing could be performed relative to the adequacy of cure, but does not seem warranted at this time.

There are several coating adhesion tests that can be performed including tape testing whereby an "X" cut is scribed in the coating through the substrate or by gluing of metal load fixtures that are removed via a pull-off gage. The latter method provides quantitative data (tensile strength in psi units). Due to (wet/recently wet) surface conditions another adhesion test method was deemed appropriate, namely, ASTM D 6677, Standard Test Method for Evaluating Adhesion by Knife. This method involves scribing an "X" cut through the coating and probing the incision. The ease by which the coating is removed, or lack thereof, and the size of the coating pieces removed is interpreted via a rating scale. Refer to Table 2 of this report for the Rating System.

In general, visual examination of the coated piling surfaces indicated reasonably good film quality without evidence of pinholes, holidays, or delaminated coating areas. The exception to this was through film cracking of the coating at a number of areas, mostly located at bends and coincidental with pile interlocks (cracks oriented vertically). See Photos 3 and 4.

However, there were through film cracks which were also horizontal in orientation. See Photo 5. Additionally, CPI observed sporadic areas of multiple and irregularly oriented short cracks. This type of cracking is typical of film curing stresses in solvent based epoxy coatings associated with excessive film thickness during application. See Photo 6. It shows this typical condition.

Please refer to Table 1. It presents the dry film thickness, substrate surface profile, solvent rub, and adhesion test results obtained in the field by CPI.

Table 1
<u>Field Test Data</u>

Sheet Pile No./Location (See Dwg.W-24)	**Dry Film Thickness (Mils)**	**Surface Profile (Average Mils)**	**Solvent Rub**	**Adhesion (*See Adhesion Rating Chart Next Page*)**
1P5 – Land Side. Zone 1	28.4 33.2 (touch-up area)	2.5	Black residual No softening	10
1P25 – Land Side, Zone 1	34.3 43.2 (touch-up area)	3.0	Black residual No softening	10
1P100 – Land Side, Zone 1	16.1 (single coat) 21.1 (single coat)	2.5	NA	10
1P175 – Land Side, Zone 1	42.0	2.5	Black residual No softening	NA
1P30 – Water Side, Zone 1	29.0 (single coat)	NA	Black residual No softening	10
1P40 – Water Side, Zone 1	37.0	3.0	NA	NA
1P130 – Water Side, Zone 1	34.0	2.0	Black residual No softening	NA
1P40 – Water Side, Zone 3	36.0	2.5	NA	NA
1P110 – Water Side, Zone 3	32.0	2.5	Black residual No softening	10

Table 2
Rating System

Adhesion Rating	Description
10	Coating is extremely difficult to remove; fragments no larger than approximately 0.8 by 0.8 mm (1/32 in. by 1/32 in.) removed with great difficulty.
8	Coating is difficult to remove; chips ranging from approximately 1.6 by 1.6 mm (1/16 by 1/16 in.) to 3.2 by 3.2 mm (⅛ by ⅛ in.) can be removed with difficulty.
6	Coating is somewhat difficult to remove; chips ranging from approximately 3.2 by 3.2 mm (⅛ by ⅛ in.) to 6.3 by 6.3 mm (¼ by ¼ in.) can be removed with slight difficulty.
4	Coating is somewhat difficult to remove; chips in excess of 6.3 by 6.3 mm (¼ by ¼ in.) can be removed by exerting light pressure with the knife blade.
2	Coating is easily removed; once started with the knife blade, the coating can be grasped with ones fingers and easily peeled to a length of at least 6.3 mm (¼ in.).
0	Coating can be easily peeled from the substrate to a length greater than 6.3 mm (¼ in.)

3.0 Technical Discussion

CPI's investigation has shown that generally coating adhesion and film quality with the exception of through film cracked areas and areas of mechanical damage was reasonably good. During construction, it was observed that wood spacer blocks used for separating the piles when they were stacked were found to be stuck to the piles and had to be hammered off. The coating was damaged in these areas when the blocks were removed indicating that the coating may have been uncured when the piles were stacked after coating application. This resulted in many damaged areas. Our findings further showed that the Macropoxy did properly cure and was resistant to the solvent rub test. The one major anomaly identified in the field was excessive coating film thickness. The overall coating thickness was specified to be two coats each applied at 10 mils dry film thickness. The measured film thickness in the field gave common overall DFT values between 28 and 42 mils. In addition, CPI noted that some areas sampled showed the presence of only one coat of the Macropoxy 646 with dry film thickness values as high as 29 mils. These results indicate that the shop coating application was neither uniform nor performed in accordance with the specifications.

When polymerized and solvent containing epoxy coatings like the Macropoxy 646 cure, stresses develop within the coating film which are oriented in all directions. When such coatings are applied at over twice their normally specified film thickness (20.0 mils achieved in two coats), the curing related film stresses reduce the coating film's flexibility significantly and increase the brittleness making the coating less resistant to flexure and impact. It is CPI's technical opinion that the excessive coating film thickness and therefore the increased film stresses resulted in a coating film more susceptible to through film cracking during the handling and installation of the coated piles on this project. The through film cracking oriented vertically was most likely the result of normal flexure of the sheet piling during handling while the horizontal cracking could have been manifested during vibratory driving of the piling. The randomly oriented and closely spaced and/or interconnected cracking observed included through film and partial depth cracking/crazing. These manifestations are typical of impact damage to brittle coating films. In short, the coating was applied too thick. There is a reason coating manufacturers are careful to specify coating thickness ranges. Too little coating thickness results in poor substrate hiding and film quality while excessive thickness causes changes in curing stresses and/or physical properties which are detrimental to coating performance. When proper surface preparation and the appropriate coating film thickness is applied, the normal handling and installation of sheet piling would not result in cracking of the coating system.

Regarding the propensity for through film cracking of the existing coating system to progress in the future, it is CPI's opinion that this should not be excessive. We base this finding on the fact that most of the flexure and impact related forces exerted on the piling occurred during shop handling, transportation, rehandling, and installation. This statement, of course, assumes that there will be some thermal related movement of the piling especially at seams in the future. This movement can and likely will result in some additional coating cracking, but we expect that it will not be extensive. When considering that most of the flexure and impact related forces are over in concert with the good adhesion and coating film quality observed at non-cracked areas of the piling sheets, we believe it is reasonable not to expect a substantive increase in coating failure manifested as cracking during the normal service life of the coating system.

CPI does need to point out that our investigation did not include coating or corrosion condition assessment of much of the bulkhead surfaces which were not visible during our site visit. Therefore, CPI cannot characterize the extent of the defects noted in this report on those inaccessible piling surfaces (below grade and submerged).

CPI also observed cracks that were coated over. See Photo 7. Those areas should be treated as recommended in Part 5.0 of this report. (Same as for cracks previously untreated.) This is not advisable to do.

4.0 Conclusions

Based on CPI's field investigation findings, we draw the following conclusions:

A. Overall, the surface preparation and resulting shop-applied coating system adhesion appeared acceptable and within specified limits for degree of cleanliness, (SSPC-SP-10). Similarly, coating film quality generally appeared good except at the cracked and mechanically damaged locations observed.

B. There was evidence of workmanship concerns whereas the surface profile of the steel where exposed by CPI revealed a peened appearance as opposed to the angular, sharp surface profile specified. CPI does not know the extent of this peened substrate appearance in the overall bulkhead piling surfaces.

C. The most salient problem identified by CPI's field investigation was the excessively thick dry film thickness of the coating system. This overly thick coating film produced film stresses related to cure that reduced the flexibility and therefore enhanced the brittleness of the coating. Subsequently, the coating film was susceptible to through film cracking when the piling was subjected to flexure and impact during handling and installation.

D. CPI does not expect similar cracking defects to extensively develop progressively over time as most of the piling movement due to flexure and impact has already occurred. This is further supported by the good adhesion and film quality findings reported earlier in this document. It is important to note that this brittleness in the coating will likely result in larger areas of coating defects when mechanical damage (impact) occurs to the sheet piling.

E. There are likely other coating defects similar to those documented above present on areas of the sheet piling bulkhead not accessible during CPI's field investigation. These include the buried portions of the piles and the underwater portions of the piles. The below waterline areas should be repaired as outlined in Part 5.0 of this report. If the same type of defects exist in the buried portion of the piles and the piling is not water tight, ongoing corrosion can be expected. The recommended action will be inspection of some representative areas of the piles to check for such damage. If present, cathodic protection of the piles will likely be the best corrosion protection option long-term as back fill removal and reinstallation may result in more coating damage.

F. CPI does not believe that laboratory testing is warranted for this project unless desired by the customer or facility owner.

5.0 Recommendations for Corrective Action

CPI makes the following recommendations for corrective action:

A. A complete inspection including underwater portions of the piles should be conducted to identify all coating cracking, corrosion problems, and other defects prior to the recoating rework planned for the spring of 2010. If significant corrosion problems are identified by that survey, the use of cathodic protection should be considered in conjunction with the planned coating repairs.

B. All through coating cracked locations should be repaired as follows:

   1. Power tool clean the crack in accordance with SSPC-SP-11 Power Tool Cleaning to Bare Metal area plus 4” on either side of the corroded crack areas feathering the cleaning onto the intact coating periphery another 2” to 3”. This can be done on one tide change.

   2. On the next tide change, pressure water wash the previously cleaned areas to decontaminate the steel. Immediately power tool clean these areas to remove flash rust corrosion product and apply the Splash Zone Coating Material in accordance with the manufacturer’s recommendations. CPI understands the approved coating repair product is FX-764 Hydro-Ester Zone and Underwater Paste. This seems like a suitable product for this application. An alternate product can be considered from Sherwin-Williams, but the FX-764 does have a proven track record on similar projects.

   3. A similar coating repair procedure should be used for areas where mechanical damage has occurred. In those cases, the power tool cleaned area need only extend approximately 4” beyond the corroding steel area.

C. The use of 3rd party independent coatings inspection (NACE trained) during the recommended coating repair work on this project should be considered along with preparation of a coating repair specification.

6.0 Referenced Photographs

Photo 1 – Zone 1 looking north. Note numerous coating touch-up areas.

Photo 2 – Typical peened surface profile.

Photo 3 – Typical vertical coating cracks. Note through-crack rust.

Photo 4 – Typical vertical coating crack associated with interlocks.

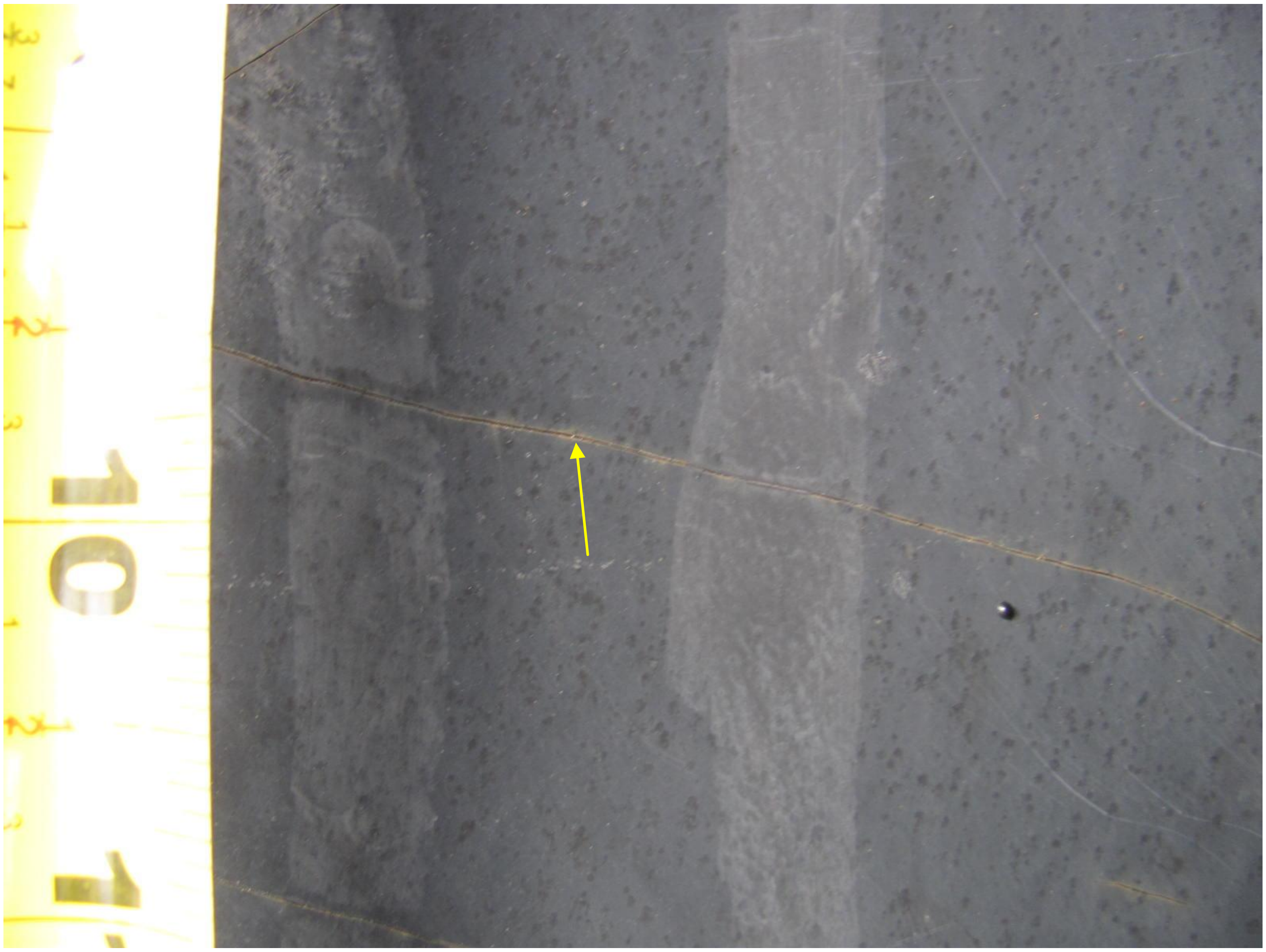

Photo 5 – Typical horizontal coating crack.

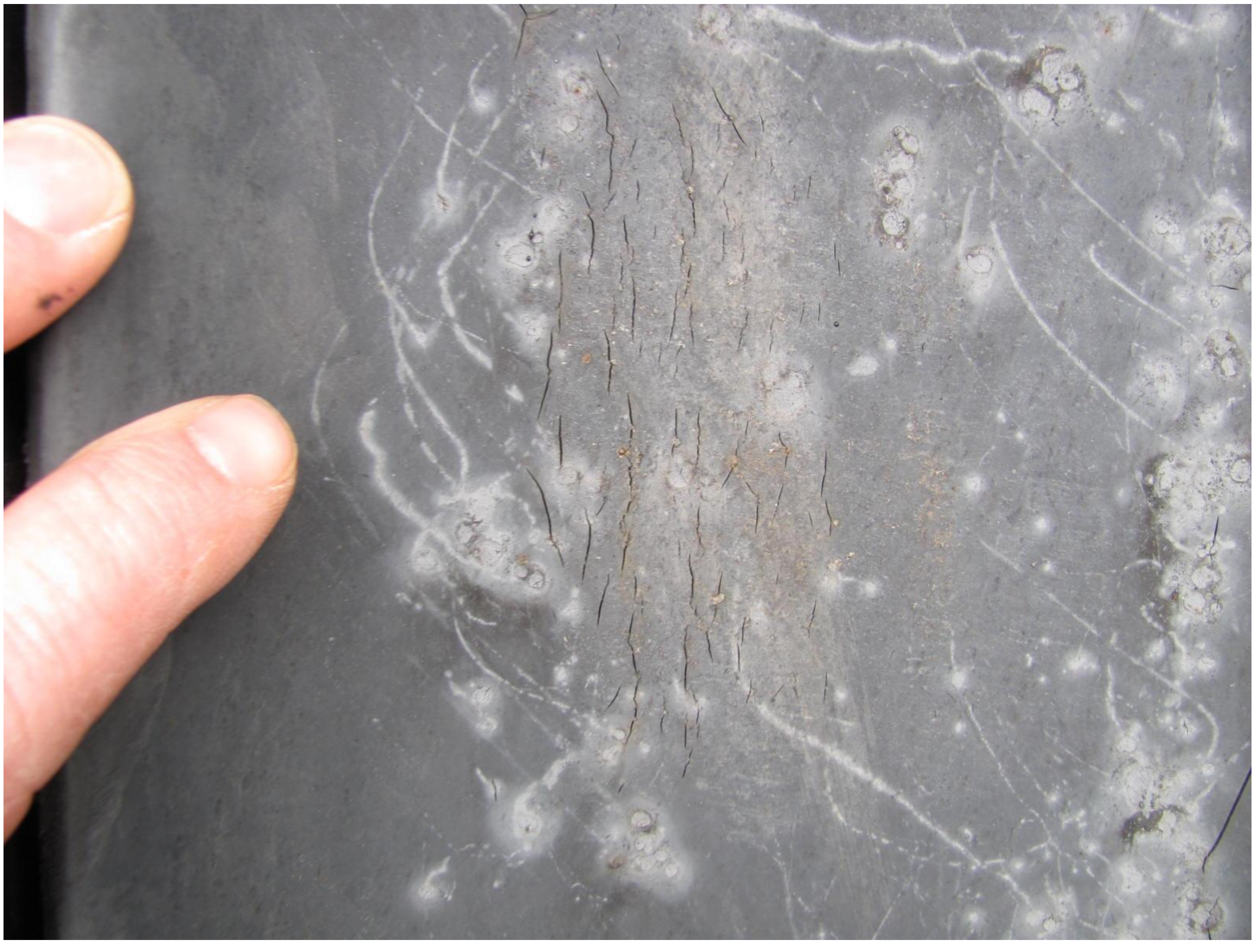

Photo 6 – Short, multiple, irregularly orientated coating cracks.

Photo 7 – Overcoating of cracks.