The Effectiveness of Petrolatum Tapes and Wraps on Corrosion Rates in a Marine Service Environment

C. Hutchinson, P.A. Farinha
and D. Vallini*

Extrin Consultants
Suite 1, 28 Burton Street
Cannington WA 6107

***Fremantle Ports**
1 Cliff Street
Fremantle WA 6160

1. INTRODUCTION

Petrolatum tapes and wrap systems have long been used as a means of managing the corrosion of steel support piles in marine service environments, particularly within pile “splash zone” locations where accelerated low water corrosion (ALWC) has been identified a major issue. However, the efficacy of these systems on significantly reducing corrosion rates over time can be difficult to accurately quantify.

The use of weight loss coupons placed under a petrolatum wrapping system is one means of quantifying the corrosion rate of steel by calculating the metal coupon weight loss over time. The corrosion morphology can also be defined over time. This data then becomes useful when compared to control coupons placed in the adjacent service environment without the protection of a wrapping system.

Corrosion rates measured using the above methodology at a Western Australian outer harbour facilities suggest the corrosion rate of steel is significantly reduced with the application of petrolatum tape and wrap systems. However, the extent of the corrosion rate reduction is a function of variables such as the quality of materials used, the material application, the local environmental conditions and the occurrence of microbial influenced corrosion.

2. BACKGROUND

2.1 TESTING OF PETROLATUM TAPE EFFICACY PERTAINING TO MARINE CORROSION

2.1.1 Causative prompt for testing of petrolatum tape efficacy

After undertaking numerous surveys at various port facilities for the Fremantle Ports since 1999, it was apparent that in some locations, corrosion deterioration to steel support piles below existing petrolatum tape wrapping systems was occurring. This was confirmed both visually and with the sequential use of ultrasonic thickness testing. In the initial surveys, the pile degradation that was being observed was mainly apparent around outer harbour facilities where the majority of emphasis on inspections was being concentrated.

The main finding associated with the degradation of steel support piles was the clearly visible corrosion degradation that resulted in an “hour glass” effect being observed on the piles at locations approximately 500mm below low water level (LWL). It has been suspected that this “hour glass” effect is a combination of corrosion processes and at a datum level which suggests differential aeration as a driving mechanism. Additionally, on removal of the sleeves and tape, the corrosion morphology of the surface was that of shiny pitted steel below thick black deposits. This observed corrosion morphology was typical of that associated with Microbially Influenced Corrosion (MIC). Samples taken and inoculated for the presence of Sulphate Reducing Bacteria (SRB) show very high counts for both sessile and planktonic bacteria with counts of 10^5/ml (planktonic) typical for this location.

Traditional corrosion management techniques employed for the protection of steel support piles in these “worse case” locations consisted of the application of a petrolatum tape to the substrate followed by the encapsulation of the pile with a electro-fused High Density Polyethylene (HDPE) sleeve. Some of these wrap systems have been in place since 1984. Over the intervening years, the external sleeves placed to provide protection to the underlying petrolatum tapes were found to loosen and move up and down the steel support piles or in some instances slide down the support pile. The subsequent movement of the sleeves provided easy access of water and subsequently nutrients between the HDPE sleeve and the petrolatum tape wrapped support pile.

It was evident from visual inspections underneath the removed tape wrap and sleeve systems, that ongoing corrosion degradation to the steel support piles was occurring despite the corrosion management techniques employed. Determining corrosion rates experienced on the piles was difficult to ascertain as replication of ultrasonic thickness testing results was questionable. As the corrosion degradation appeared so pronounced, it was important that more accurate determination of corrosion rates be ascertained to allow port management to accurately manage their assets. Additionally, being aware of corrosion rates being experienced would also test the efficacy of implemented corrosion management strategies such as the current steel support pile petrolatum tape and HDPE sleeve systems.

As a result of the findings, it was determined that to provide “real time” corrosion rates associated with the steel support piles below protective wrap and sleeve methodologies, corrosion weight loss coupons would be the best approach.

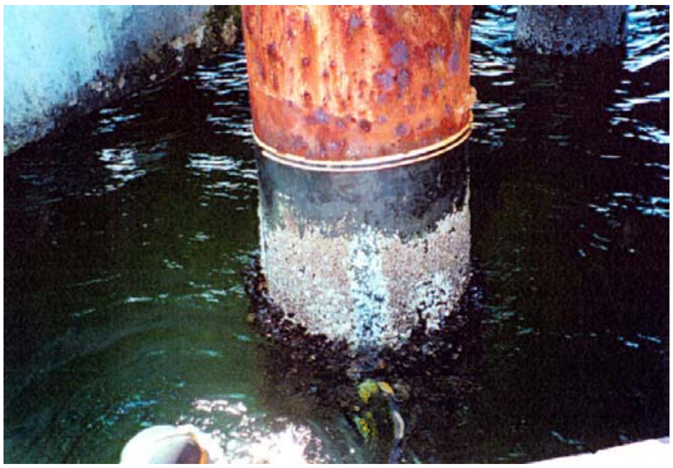

Fig I. View of standard electro-fused sleeve system

Fig II. View of new tensioning rod sleeve system with additional atmospheric zone tape wrapping.

3. IN-SITU TEST DESIGN

The first set of weight loss or “mass loss” coupons were placed on steel support piles in 1999 and were placed under the original standard sleeve protection system. The results of these tests confirmed that corrosion to the steel support piles was still occurring below the implemented corrosion management system and warranted review to provide a more successful long term corrosion management approach. Subsequently a second set of weight loss coupons were placed on steel support piles in 2003 below a revised tape wrap and sleeve arrangement that had been designed to significantly reduce the occurrences of both aqueous marine corrosion and MIC [1] & [2].

3.1 Petrolatum tape and sleeve systems analysed for performance

The original steel support pile wrap and sleeving system consisted of the application of a standard petrolatum tape followed by the encapsulation of the steel support pile with a electro-fused HDPE sleeve. The sleeve was then fixed using a mix of materials for strapping, including stainless steel and polyethylene. It was clearly evident from the results of the weight loss coupon trials undertaken over a two year period that the system was not adequately reducing the incidence of corrosion to the steel support piles (See Section 4 for test results).

Due to the findings of the initial testing, an investigation into a revised system based on the principles of the existing wrapping and sleeving methodology was implemented. The first change to the system was the installation of a petrolatum tape, the grease of which was dosed with a proprietary biocide in an attempt to reduce the colonization of (SRB) and thus reduce the incidence of MIC. The second and most important alteration to the system was the changes made to the external sleeving fixing arrangement. The original sleeve consisted of a 2mm thick HDPE sleeve which required electro fusing along the longitudinal seam to close the sleeve. Additionally, various bands of both non-metallic and metallic were incorporated periodically around the sleeve to hold the sleeve tight around the steel support piles. The newly specified sleeving system consisted of a thinner and more flexible poly vinyl/polyester that is fixed via a longitudinal tensioning rod system that provides for a more contour fitting than the original system. Correct tensioning prevents water flow between the jacket and the applied tape system.

3.2 Coupon preparation and placement

3.2.1 Weight Loss Coupon Preparation

All weight loss corrosion coupons were fabricated from standard carbon steel of 2mm thickness cut to 100mm x 75mm and attached to the pile via a threaded steel rod that was welded to a supporting backing plate and then to the pile.

Each coupon was individually punched with a reference number for future traceability. The coupon surface was abrasive blasted using garnet media to achieve a 40micron profile and cleaned in an ultrasonic bath containing Iso-Propanol for 10 minutes. The coupons were accurately weighed on an analytical balance without the respective rod and backing plate attachment. The coupons were stored in a vacuum sealed desiccators containing desiccants to prevent moisture and oxidation until they were placed onto the individual steel support piles.

3.2.2 Weight Loss Coupon Pile Location

The steel support pile locations selected for the trials consisted of 2 piles from a berth situated at the extremes of the main outer harbour facility and 2 piles from the jetty access or neck leading to the main berth. During the second trial conducted with the new tape wrap and sleeve system, an additional pile was selected at each location to provide information on actual marine corrosion rates in the area. At each location, one of the three piles was nominated the control pile for the project. Coupons placed at the two control piles were fixed to the pile but outside of the new protective sleeving system thus simulating corrosion rates on unprotected steel in the immersed marine environment at this location.

Each of the steel support piles selected for the test had duplicate coupons fixed to the north, south, east and west faces.

All coupons were placed at +500mm from the bottom of the High Density Poly Ethylene (HDPE) sleeve on the piles or more specifically at low water mark RL 0.00m. This level was chosen due to results of previous NDT surveys indicating this location to be within the zone of most corrosion degradation being experienced by the steel support piles. This level is also within the extent of the pile wrapping system to be fitted, which is located between RL +1.50m and RL -0.50m.

All Levels in this report are relative to the Low Water Mark (Fremantle Datum).

3.2.3 Weight Loss Coupon Placement – monitoring pile

The placement of the weight loss coupons on each of the monitoring piles was undertaken as follows: **Refer to Fig IV & V**

- All test piles were first high pressure water washed with garnet inclusion to class 2 over area to be protected.
- Weight loss coupon backing rods/plates (which provided a 5mm stand-off) were then welded to the steel support pile at RL 0.00 and situated 500mm above the bottom level of the sleeve to be placed.
- The entire prepared pile surface had an application of petrolatum primer.
- Coupons greased and placed onto backing rod/plate.
- Petrolatum tape applied in accordance with the manufacturers recommendations with minimum 55% overlap.
- Outer sleeve installed and welded/tensioned accordingly.

As the intent of the work was to establish whether corrosion was occurring beneath the sleeved, wrapped piles, the weight loss coupons were made electrically continuous with the piling. Hence corrosion rates similar to that being experienced on the piles were obtained.

3.2.4 Weight Loss Coupon Placement – control pile

The weight loss coupons at the two control pile locations were fitted outside of the installed pile wrapping and sleeving system to enable "real time" corrosion rates to be calculated to compare against those corrosion rates experienced below the tape and sleeve systems. The coupons were first fixed to a specifically designed round steel bar supporting bracket. This steel bar was welded above and below the pile sleeving system and bent at 90^{o} to provide a parallel to the pile surface attachment point approximately 100mm offset from the wrapped pile face. The placement of the weight loss coupons was such that it placed them within the zone associated with Accelerated Low Water Corrosion (ALWC) and typically protected by the placed sleeving systems. **Refer to Fig III & V**

Fig III. View of weight loss coupon control pile being fitted by a diver.

Fig IV. View of tensioning rod sleeve weight loss coupon pile.

3.2.5 Weight Loss Coupon Exposure time

For the initial weight loss coupon trials conducted on the original tape and sleeve system (electro-fused) the coupons were exposed for 365 days.

For the weight loss coupons placed under the revised protective tape wrap and sleeve system (tensioning rod) the coupons were removed at 368 days with the second stage of removal scheduled for February 2005.

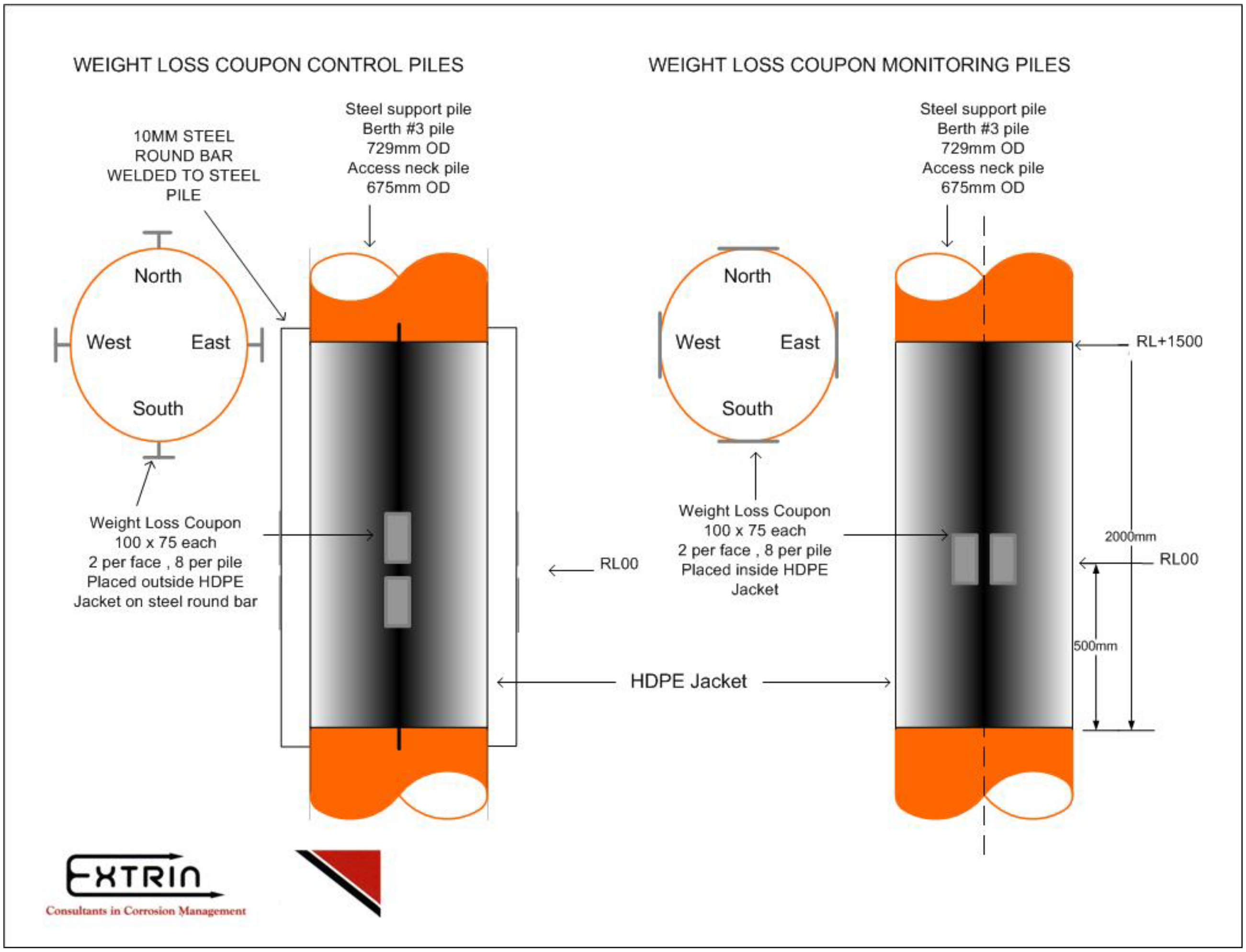

Fig V: Drawing showing weight loss coupon arrangement on weight loss coupon control piles and monitoring piles.

4. TREATMENT OF WEIGHT LOSS COUPONS AND CORROSION RATE CALCULATION

4.1.1 Weight Loss Coupon Removal

The weight loss coupons were individually removed from the steel support piles as follows:

- Removal of sleeves by unbolting existing tensioning rods (four sleeves in total)
- Cutting a window in the grease tape to expose the weight loss coupons.
- Photograph the weight loss coupons before removal.
- Removal of the weight loss coupon one from the southern face and one from the northern face.
- The area from where the coupons removed were then well greased. A patch application of the grease applied prior to the replacement of the existing sleeve system and repaired, to leave the sleeve intact and operational.

Prior to undertaking the weighing of the weight loss coupons, the coupons were first scraped clean with a non-metallic spatula to remove as much excess grease as possible. The remainder of the residual grease is cleaned under running hot water with detergents. The coupons are then suspended in a solution of Isoproponal alcohol for 5 minutes followed by additional cleaning in an ultrasonic bath. The coupons are then dried with hot air prior to weighing.

To ascertain the weight loss of the individual coupons the weight loss is converted to average corrosion rate (R), as follows:

$$\boldsymbol{R} = \frac{(W1 - W2) * (365)}{(A) * (d) * (D)}$$

Where:

W_1 = Initial coupon weight (g)
W_2 = Final coupon weight (g)
A = Coupon area (cm^2)
d = Metal/alloy density (g/cm^3)
D = Exposure time (days)
R = Corrosion-rate (mpy)

The above equation was sourced from the Technical Report on Corrosion Coupons and Weight Loss Analysis, Metal Samples Corrosion Monitoring Systems, Alabama, AL 36268, USA.

Pile No	Coupon No	Exp. Time (days) (D)	R – Corrosion Rate. (microns/year)
Corrosion rate of coupons placed inside the petrolatum tape and tensioning rod sleeve system after 368 days exposure			
17S	17S # 32 (NR)	368	0.03
17S	17S # 41 (SR)	368	No Corrosion
51N	51N # 44 (SR)	368	No Corrosion
10E	10E # 5 (SR)	368	No Corrosion
62B	62B # 9 (NR)	368	No Corrosion
51N	51N # 26 (NR)	368	No Corrosion
10E	10E #1 (NR)	368	0.07
62B	62B # 16 (SR)	368	No Corrosion
		Highest value	0.07
Corrosion rate of coupons placed on the control piles exposed to the marine environment for 368 days			
34S	34 S # 48 (ST) A	368	595.52
34S	34 S # 48 (ST) B	368	598.21
36D	36D # 13 (ST) A	368	612.38
36D	36D # 13 (ST) B	368	613.52
36D	36D # 13 (ST) C	368	613.74
36D	36 D # 27 (NT)	368	611.90
34S	34 S # 46 (NT) A	368	576.65
34S	34 S # 46 (NT) B	368	611.28
		average	604.15
Corrosion rate of coupons placed inside petrolatum tape and electro-fused sleeve removed after 365 days exposure			
4D	9	365	9.7
4D	10	365	6.9
8A	16	365	2.1
8A	17	365	5.3
68A	21	365	1.6
68A	22	365	7.8
79E	3	365	.4
79E	4	365	3.5
		average	3.4

*** Negative sign denotes negligible corrosion rate, allocated as zero (0).**
Chemical Balance error ± 0.0005 gram.

Fig VI: Table showing results of weight loss coupon trials conducted on original tape wrap and electro-fused sleeves, control piles with no protection and on revised petrolatum tape and tensioning rod sleeve systems.

5. INTERPRETATION OF WEIGHT LOSS COUPON TRIALS

5.1 Visual Assessment

The first noticeable finding with the two separate weight loss coupon trials was the importance of tightness or fit of the sleeves over the piles. The older original electro-fused sleeves although tight around the sleeve, did not contour the pile or adequately seal at the top and bottom which allowed for the ingress of water and nutrients with the tidal action. The new sleeve system incorporating the thinner sleeve material and tensioning rod system provided a far superior fit with the sleeve molding to the contours of the already corroded pile surface. This tightness of fit preventing any possible water flow between the sleeve and the tape/pile surface. **Refer to Fig VII**

When removing the coupons after approximately 12 months service exposure, the difference in visual findings was significant. When removed, the older type sleeve showed the tape to be discolored black and the exposed coupons had significant dark black corrosion product (iron oxides or sulphides) and a more adherent red corrosion product (iron oxides) over 30-60% of the surface. In addition, there was the smell of rotten eggs (hydrogen sulphide) with some gas bubbles liberated from below the sleeving. Alternatively, the coupons associated with the newer sleeve system showed no sign of degradation whatsoever after the 12 month exposure. Additionally, the grease tape below the sleeve was firmly intact with minimal discoloration or breakdown evident when compared to the original system.

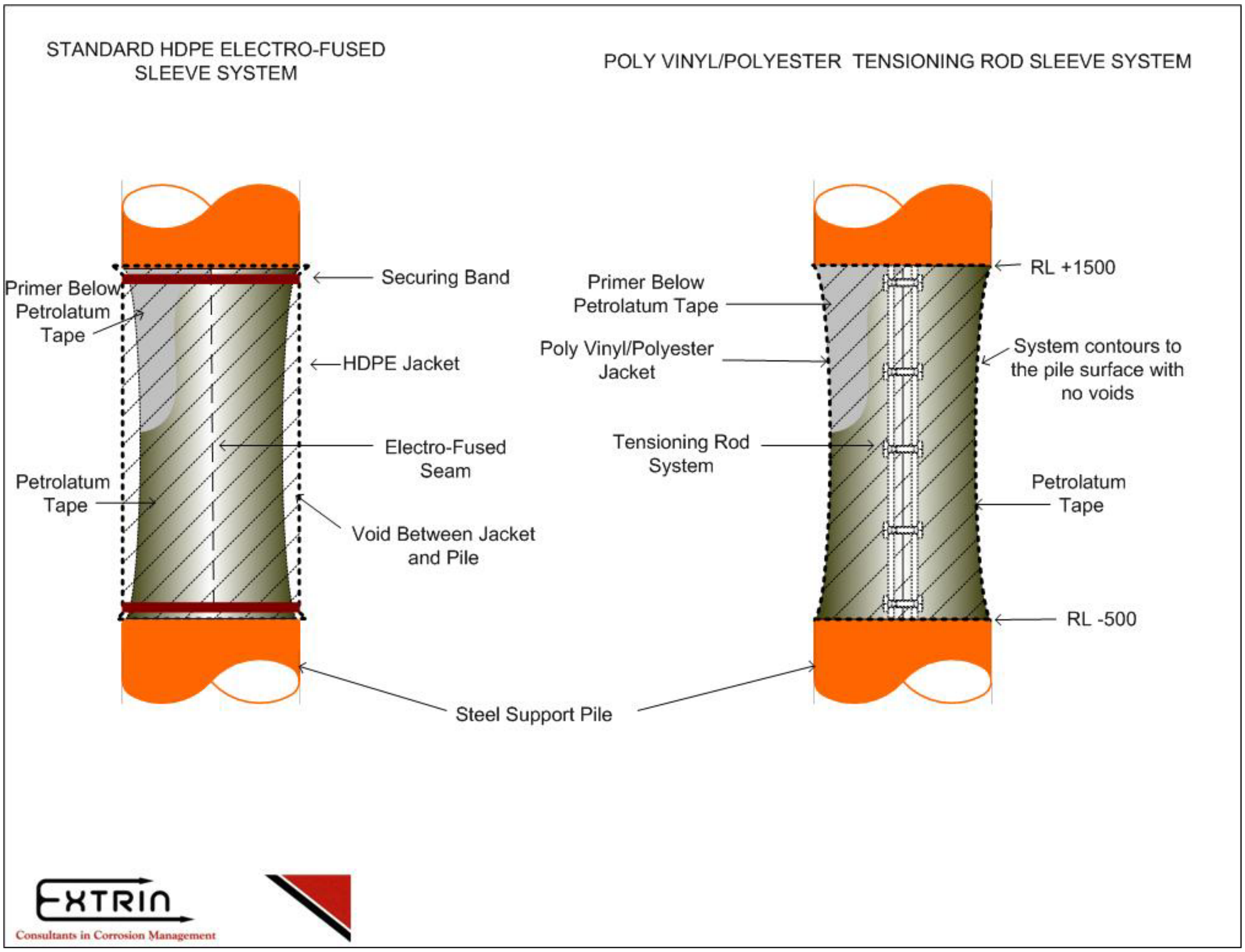

Fig VII. Drawing showing standard HDPE sleeve system and tensioning rod sleeve system at locations of "hourglass effect". Note how the tensioning rod sleeve system contours to piles surface thus reducing water/nutrient flow into and behind the sleeve system.

Fig VIII. View of weight loss coupon removed from below tensioning rod sleeve system prior to cleaning.

Fig IX. View of weight loss coupon removed from below tensioning rod sleeve system after cleaning.

Fig X. View of weight loss control pile coupon prior to placement outside sleeve systems. (75 x 100mm)

Fig XI. View of control pile weight loss coupon after 368 days exposure.

5.2 Weight loss coupon analytical data

Review of the final results show that corrosion degradation is significantly less below the newly introduced tape wrap and tensioning rod sleeve system over the old tape wrap and electro-fused sleeve system. The weight loss for the original tape wrap and electro-fused sleeve system employed for steel support pile protection gave an average corrosion rate of 3.4 microns/yr . The corrosion rate for the re-designed system specified in 2003 gave an average corrosion rate of 0.07 microns/yr, which is negligible.

Review of the graph in Fig XII clearly shows the difference in corrosion rates between the older type electro-fused system versus the newer tensioning rod sleeve system.

During the weight loss trials in 2004, control piles were also used to ascertain true corrosion rates for the marine environment to which the steel support piles were exposed. The results for the control pile coupons gave an average corrosion rate of 604 micron/yr, but this was based on the original surface are of 150 cm2. However, with the control coupons, the surface area was being reduced, until at completion of the test only about 10 - 15% of the original coupon remained (see Fig XI). This would therefore compare favourably with expected corrosion rates in an Accelerated Low Water Corrosion environment of 1100 – 1200 micron/yr.

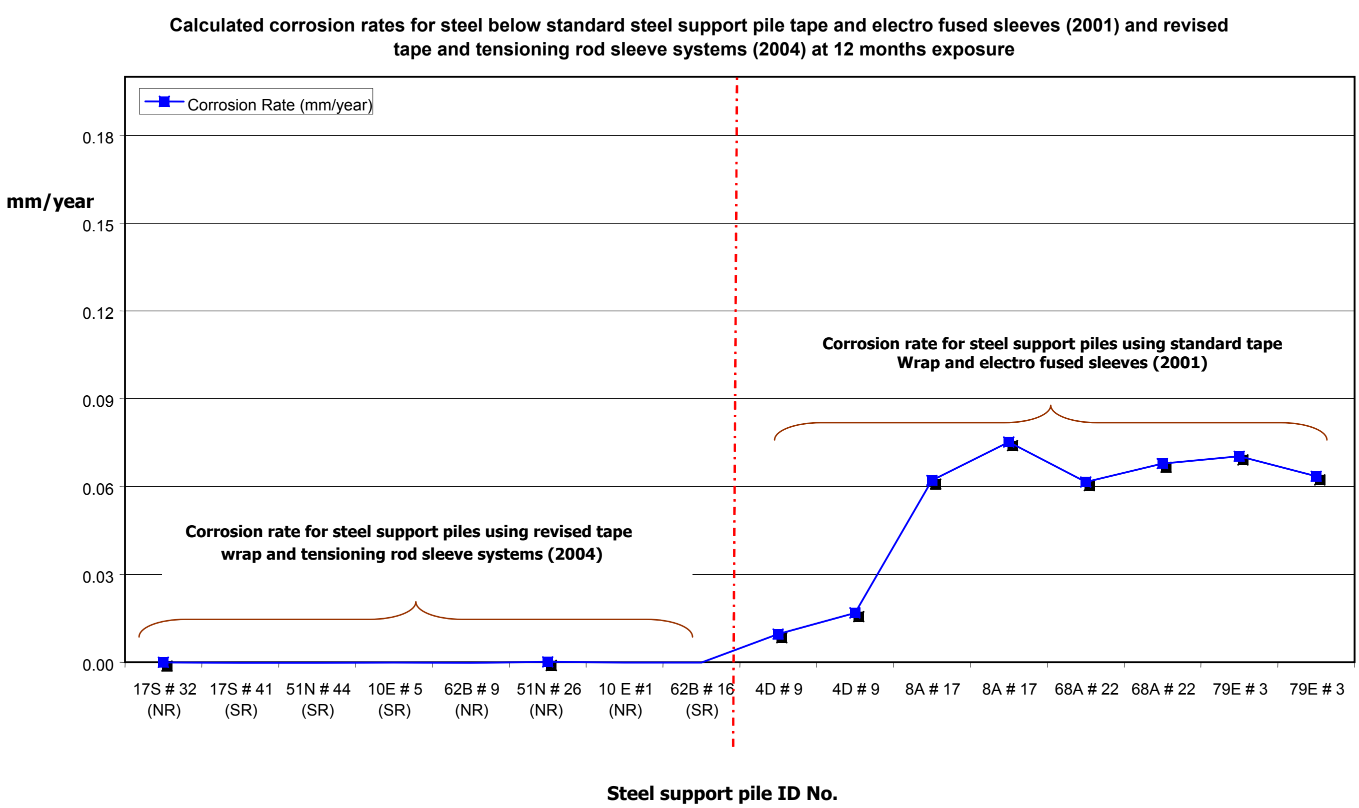

Fig XII. Graph comparing corrosion rates between the standard electro-fused sleeve system versus the new tensioning rod system.

5.3 Microbial testing

A sample of corrosion product was taken from the removed coupons at each test pile location. This corrosion product was cultured for SRB using a *Bio San Sanicheck SRB test Kit*. All attempts were made to inoculate with the corrosion sample and to have minimal inclusion of the surrounding sea water so that the SRB numbers returned were indicative of the sample product rather than the bulk solution. With the older sleeve systems, after only 24 hours of incubation, the inoculated corrosion product vial returned a positive result and as such the estimated bacterial count was approximately 10^5/ml. This constitutes an extremely high SRB rate and therefore elevated corrosion rates would be expected.

Due to the extremely high numbers of bacteria noted in this preliminary test for SRB presence, further inoculations were conducted by third party laboratories to cross reference SRB counts. Approximately 1 cm of the blackened metal surface was swabbed and then cultured for SRB. The seawater surrounding the coupon trial locations was also cultured for SRB.

10 ml of neat samples were cultured for SRB by inoculation of routine double strength Postgate's medium with an equal volume of sample. Tenfold dilutions were made of each sample in appropriate diluting fluids and sub-samples of each dilution tested for SRB and iron bacteria using recommended culture media. The incubation temperature for all cultures was 30^oC and all samples were tested in duplicate.

Deposit scrapings taken from the original trial coupons returned SRB enumeration's of 10^6/cm consistent with the level of bacteria found using the Biosan quick check test. Those coupons tested from below the new tensioning rod sleeve system returned negligible counts for SRB. Analysis of sea water surrounding the submitted coupons returned SRB counts of 10^5/ml. These results confirm the preliminary count for SRB numbers and must be considered as very significant as a cause of microbially influenced corrosion.

In summary, review of the analytical test data from the sampling of both the waters and the test coupons revealed significant information about the sleeving systems.

1. The waters in the vicinity of the steel support piles have high bacterial counts (10^5/ml).
2. The coupons removed from the original sleeve system returned SRB counts of 10^6/ml.
3. The coupons removed from the revised tensioning rod system returned negligible SRB counts.

The significant reduction in SRB counts on the coupons associated with the newer sleeve system does appear to be a factor of the reduction in water/nutrient flow in behind the sleeve system.

Recently, tape manufacturers are also providing new petrolatum tapes impregnated with biocides. These tapes will have benefits, yet it is important that the manufacturers are transparent as to the type of biocide that has been introduced into the tape. Making sure that a site experiencing corrosion degradation as a result of high SRB numbers receives a tape with a biocide specific for the control of SRB rather than a broad spectrum biocide will ensure that the tape provided is suitable for the corrosion management required.

6. ACCELERATED LOW WATER CORROSION AND MICROBIALLY INFLUENCED CORROSION

6.1 Accelerated Low Water Corrosion

Accelerated Low Water Corrosion (ALWC) has been described by BS 6349 Part 1 Maritime Structures section 7 materials, clause 5.2.2 as " concentrated corrosion, being 'local' and 'accelerated' corrosion in relation to 'normal' sea water corrosion." Accelerated low water corrosion (ALWC) occurs just below the tidal zones, reportedly due to the influence of microbial activity on the steel surface. In such situations corrosion can proceed about ten (10) times more rapidly than normal. ALWC is usually visually manifested by bright orange patches overlying a black sludge with a shiny pitted steel surface underneath, and usually results in corrosion rates of up to 800 microns/year for bare steel pilings[2].

A common misconception is that ALWC is a concentration corrosion issue or one form of corrosion, whereas it is more accurately described as a combination of several different corrosion mechanisms that is microbially assisted. Along with differential aeration, aqueous corrosion and atmospheric corrosion when exposed, ALWC combines Microbially Influenced Corrosion (MIC) as a microbial and/or fungal mix associated with corrosion.

ALWC is typically identifiable at locations just below low water level and as such it is often hidden and goes unnoticed in many instances. The concern with ALWC is that it is rapid in its attack with corrosion rates of 1mm and higher being typical in these zones, remembering that typical marine corrosion results in a metal loss of 0.1 – 1.0mm/yr [4].

6.2 Microbially Influenced Corrosion

Microbiological Influenced Corrosion (MIC) is believed to be responsible for approximately 20% of all corrosion [3].. As a phenomenon, MIC is accepted as likely when suitable nutrient, flow and environmental conditions occur, along with the presence of corrosion enhancing bacteria. MIC can then be quite rapid in its attack, with pitting at a rate of 5 – 10 mm/yr possible. The main types of bacteria associated with corrosion are SRB, Metal Reducing bacteria (MRB), Metal Depositing bacteria (MDB) and Acid Producing bacteria (APB). At the port in question, the bacteria most responsible for the observed degradation was the SRB.

The most obvious signs that MIC is evident on structures experiencing ALWC is the familiar tell tale sign of an "orange bloom". This bloom has become an accurate indicator of active MIC and more particularly the presence of (SRB). To date, although orange blooms are recognized as a tell tale sign of ALWC, no identification of the organisms which make up the "orange bloom" have been conducted. Currently, microbial and analytical testing is being conducted to identify the "orange bloom" constituents at Fremantle Ports.

During the trials, and subsequent surveys, it has become evident that the extent of biofilm does influence corrosion as observed on the steel support piles where no protection is evident [5]. The influences that these biofilms have on corrosion can be separated into three categories:

- The production of chemical concentration/differential aeration cells.
- The production of both organic and inorganic acids as metabolic by-products.
- The production of sulphides in deoxygenated or anaerobic environments.

Corrosion by SRB has been well documented. The corrosion morphology of the underlying steel is almost always localised and the pitting tends to be smooth and hemispherical. The microbes can be waterborne, and they can exist under a protective tubercle or other protective material (protective tape systems/fouling) that allows for an anaerobic environment on the substrate surface. Because of the extremely localised attack of these bacteria, the degradation to the steel surface at these locations can be extremely severe, while the surrounding substrate may show minimal (if any) signs of deterioration.

In the past, it was generally thought that SRB could influence the corrosion of steel in only completely anaerobic conditions. Recently, it has been recognised that corrosion by SRB can take place in relatively aerobic conditions. In these latter cases, anaerobic microenvironments can exist under bio-deposits of aerobic organisms, in crevices built into the steel structure, and flaws in various types of protective coatings. The most corrosive environments are often those in which alternate aerobic-anaerobic conditions exist because of the action of variable flow of nutrient laden water as is present at Fremantle Ports outer harbour facility [6].

Fig XIII. View of steel support pile showing "orange bloom" of about 500mm x 700mm associated with Microbially Influenced Corrosion (MIC).

Fig XIV. View of steel support pile showing "orange bloom" removed, revealing shinny pitted steel below.

8 CONCLUSIONS

The effectiveness of petrolatum tapes and wraps on corrosion rates in a marine service environment is clearly beneficial as shown by the weight loss coupon trials conducted and presented in this paper. Trials and investigations have shown that the efficacy of these systems are highly dependant on several main application factors, including:

- The suitability of surface preparation
- The extent and application success of petrolatum primers to the substrate
- Ensuring that the tapes applied are well overlapped and tightly wound
- Sleeve systems are tightly secured

The performance of two systems was tested as part of these trials with the newer tensioning rod sleeve system proving, after a brief 12 months exposure, that its ability to provide a uniform fit to sometimes corroded surfaces provides for a significant reduction in yearly corrosion rates.

As a result of these trials and other inspections, it has been proven that the move from the traditional electro-fused sleeves to the newer system was a significant move forward for Fremantle Ports in the continued management of corrosion issues due to ALWC.

The trials reported herein were undertaken under strict supervision to ensure that all avenues of manufacturers preparation and application specifications were adhered to. With some larger projects requiring hundreds of piles to use this corrosion management technique, and based on the majority of works being undertaken below water level, it is sometimes difficult to perform QA/QC inspections on all piles. Random inspections and diver/applicator awareness will go a long way in providing a long term solution to the corrosion management of steel support piles in the marine environment.

The weight loss coupon trial below the tensioning rod system is continuing with the next coupons being removed in February 2005.

Acknowledgement: The authors would like to thank Nathan Fernance for his input and drawings compiled for this paper.

References:

[1]. Fremantle Ports Weight Loss Coupon Trial Report, Extrin Consultants – 2544/01, November 2001. Farinha. P & Hutchinson. C.

[2]. Fremantle Ports, Corrosion Rate Assessment Weight Loss Corrosion Coupon Trial, Extrin Consultants – 2682/04, February 2004. Hutchinson. C & Coimbatore. V.

[3]. ASM Handbook, Volume 13 Corrosion, ASM International pp, 41,42. March 1996.

[4]. Concentrated corrosion on marine steel piles – A practical introduction Christie, J, Port Technology International, Edition 13, p 93-96, 2002.

[5]. Biotechnology Handbooks . Volume 8, Sulfate – Reducing Bacteria. Larry L. Barton University of New Mexico. Plenum Press. New York. 1995.

[6]. Economical and Technical Overview in Microbially Influenced Corrosion of Materials. E. Heinz, HC. Flemming, W. Sand (Eds). Springer-Verlag Berlin, Heidelberg, 1996.