CHAPTER 19

CORROSION STUDIES OF STEEL PILING IN SEA WATER IN BOSTON HARBOR

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INTRODUCTION

A vital problem which has resulted from our present economic justification of the use of steel piles in all of the Port's waterfront terminals is the corrosion of the piles in sea water. The selection of some type of steel piles was not made on the basis of greater resistance to fire and marine organisms, but for purely economic reasons. Timber piling has its marine borer problem, and steel has its corrosion. In this article there are three thoughts which I hope to convey to every engineer engaged in coastal engineering, namely:

(1) Each project's corrosion consideration should be treated as a distinct and separate study in designing a pile-supported structure, based on investigation of adjacent local conditions.
(2) There is nothing universal about the pattern or rate of corrosion to be expected; it is subject to many variables.
(3) Provisions or measures to mitigate or eliminate corrosion should have economic justification consistent with the planned life expectancy of the study.

With the greater use of steel piles we naturally become more conscious of this vital problem of corrosion. In order to keep informed as to the correctness of our design criteria and to evaluate protective coatings for the mitigation of corrosion, the Authority has started a regular program for the periodic examination of steel pile structures in Boston Harbor. At the present time we have utilized outside marine divers in collaboration with the William F. Clapp Laboratories, Inc., for our own structures. It is expected that we shall very shortly revive our own diving unit, which prior to World War II made examinations of all timber structures in the Harbor. The diver would have to undergo an extensive course in corrosion pattern recognition, location of possible accelerated activity, measuring procedures and description of observations; otherwise the value of the work would be questionable. Whenever a steel pile is removed, regardless of by whom, we attempt to get all the corrosion information and data before the pile is disposed of. We also have been most fortunate in obtaining the cooperation of other interests in the Harbor who have steel structures, in making similar examinations for their own information as to the existing condition of the piles and for our compilation of corrosion data.

Investigation and studies made of existing structures in Boston Harbor indicated a great range of pattern and rates of corrosion which refute widespread concepts accepted by many design engineers, such as that:

Fig. 1. Corrosion pattern on unencased pile.

Fig. 2. Corrosion pattern on encased pile.

(1) Corrosion rate is uniform throughout the entire length of pile, and that a 10 per cent additional allowance of steel in the section of the member would provide a life expectancy of 40 to 50 years. The 10 per cent has been increased by many to 20 per cent.
(2) All types of steel piles have the same corrosion pattern and rate.

In this short article it is impossible to cover the subject with any degree of thoroughness. Some of the findings described herein are no doubt startling to many. These are just a few of the actual conditions, to emphasize the need for better understanding of the problem, and not with any intention of being spectacular.

TYPICAL EXAMPLES

At one location two steel "H" bearing piles were removed from sea water after 11 years of service. These two were about 12 feet apart. One had concrete encasement to low water, and the other no protection of any kind. The corrosion pattern was entirely different in each case. The encased pile had a more or less uniform corrosion rate consisting mainly of grooves as shown on Figure 1. The plain pile had a severe attack at low water with a pattern consisting of pits as shown on Figure 2. The maximum loss of metal in the cross-section of the encased pile was about 3 per cent, whereas the other had a loss of 10.4 per cent occurring at approximately the extreme low water line, with an insignificant loss for the remainder of the length. The loss of 10.4 per cent of the plain pile does not appear alarming until you analyze it from a structural standpoint. The loss occurred at the edges of the flanges, which would normally be expected in galvanic action resulting from the differential of oxygen concentration. Structurally the loss takes place in the worst part of the member, the weak axis.

As an example of the seriousness of this loss, take a 14 inch 73# bearing pile with an unsupported length of 48 feet. A reduction in the radius of gyration from a 10 per cent loss of metal at the ends of the flanges results in a 44 per cent decrease in the allowable load on the pile. Under this degree of corrosion attack it would be impractical and uneconomical to provide a sufficient cross-section of metal to sustain such a loss over a great period of time.

Since this accelerated attack took place below the normal water level and the pile was covered with a thick growth of marine organisms, discovery of the accelerated attack is not likely by visual observation. Unless periodic examinations by a competent diver are made to discover such critical conditions, collapse of the structure would be imminent.

Pursuing this investigation and study further along, the owners of a wharf made a random inspection of 8 piles in place, selected as representative of the areas in which each was located. This was done in order to verify the following finding:

Low water accelerated attack does not occur on the encased piles, and grooving with a more or less uniform corrosion loss is also a characteristic of the encased piles.

This finding was found to be correct. It was also found that the seaward most piles had evidence of greater corrosion rate. The reason for the latter is rather difficult to explain, since it occurred not uniformly, but somewhere between the lower zone of a breaking wave and the location of the propeller of a deep-draft vessel. In attempting to ascertain the cause of the grooving corrosion pattern, a number of experts were consulted. It was the consensus of opinion that this peculiar pattern was caused by stress weaknesses in the mill scale as a result of the rolling, storage, transportation or handling process. The breaks in the mill scale become anodic and the scale cathodic in the galvanic cell. This is evidenced by the calcareous coating on the mill scale surrounding the corroded areas. The rather difficult observation to explain is the presence of no grooving on the plain pile, which had a pit pattern. The question remains as to whether this is a coincidence or whether there is a definite relationship.

At the location of our new Hoosac Pier No. 1 the former terminal had a steel sheet pile bulkhead which was installed in 1935 and removed in 1943. Thickness measurements taken at the time of removal showed tremendous loss in a short period of time. At this point the salinity of the water is reduced by an inflow of fresh water above this location, and is also polluted from a sewerage overflow discharge line. Four random piles were measured, but there was no similarity of attack common to all. The record contains no apparent cause for this abnormal severe attack, which contains very little localized pitting. The legs or flanges of the DP 1 Section had a greater rate of corrosion than the web. The more or less uniform attack from the mud line to the top of the pile in the splash zone is difficult to understand in view of well-established concepts as to the areas of accelerated attack, namely, just below mean low water, and the splash zone above mean high water. At this location in 1948 the steel sheet pile bulkhead type of quay wall was constructed for the new Hoosac Pier No. 1. Before driving the sheeting that portion above 3 feet below mean low water was flame cleaned of mill scale and rust, and then coated with bitumastic enamel. Annually the sheeting is examined by a diver for accelerated corrosion. To date nothing had developed requiring remedial action.

Also involved in the submarine examination of steel piles is our desire for information on grooving adjacent to welded splices caused by galvanic action between the bare metal at the weld, which is anodic, and the cathodic mill scale. To date we have found little evidence of such phenomena.

Cylindrical steel piles and caissons have also been examined, and found to have a good performance as regards corrosion. The absence of edges prevents galvanic current concentrations, especially at the low water area. The caisson examination indicated a very puzzling observation. The caissons on the opposite side of the pier are not coated. Because of the very large diameter, and the fact that they are filled with concrete, an accurate verification would be difficult. There is very little pitting, indicating a uniform pattern.

ECONOMIC JUSTIFICATION OF PROTECTION

There are many protective systems to mitigate or completely eliminate corrosion for a given period. The anticipated life of the new piers of the Port of Boston Authority is between 40 and 50 years, after which the piers become obsolete, and should be reconstructed to fit the needs of that time. Other structures may have different life expectancies; therefore, the measures to attain the required life should be justified economically consistent with the planned life, meaning that one with a 15-year life should not necessarily have the same protective measures as one with a 40-year life.

The greatest boost given to overcoming sea water corrosion is cathodic protection, for it has proven positive, it can be installed at any time after completion of a structure, and it protects the most difficult section, which is below the surface of the water. Although cathodic protection is the only practical means of prohibiting corrosion below the surface of the water, there are many protective measures for the zone above, such as metal jackets, organic coatings, metal coatings, greases and wrapped plastic coats. In spite of the number of methods for the tidal and atmospheric zone, there is still a need for improvement - some of the methods are too expensive, and other have too short a life for economic justification. There are many factors to be considered in protective coatings. The degree of preparation of the steel surface required; setting time, especially for recoat jobs in the tidal zone; the number of applications for a complete system; resistance to abrasion; the size of the project; and the anticipated protective life. In sandblasting steel there are 3 classes which indicates the wide range one can expect in cost and quality:

(1) Primary, which removes all loose scale and rust;
(2) Intermediate, which removes all scale to gray coating;
(3) Complete, all scale taken off to bright metal.

An average good coating will have an effective life of about 5 or 6 years. Poor coating, including poor workmanship, will fail in less than a year, with the best going to an 8 to 9 year life.

This is an example of the economic analysis that has been made on insuring a pier life expectancy of 40 to 50-years as it affects the corrosion of piles. The recommended protective system in this case consists of cathodic protection below the water and organic coatings above. The cost of this system of protection for the period starting upon completion of the structure is as follows:

Cathodic Protection	$360,000.
Protective Coatings, using re-coating every 5 years	$480,000.
	$840,000.

The steel sheet piles could be replaced in 20 years to stand up for another 20-year period, at a cost of $560,000. This is the plan accepted to insure the investment for the anticipated life.

The logical action to take in many cases, if it is determined that protective measures will be needed immediately upon completion of a large waterfront structure, is to use a more costly type of substructure which will not require a continuous protective program. However, in cases where accelerated corrosion is discovered after completion of a structure, the only alternative is the system using cathodic protection for below water, and coatings or jackets above.

CONCLUSION

This article is intended to stimulate the need for giving more thought and analysis to each waterfront corrosion problem, for continual observation of existing structures, and research for more economical protective measures. The findings and discussion herein precented are not meant to be taken as any criteria for the corrosion pattern, rate, and means of mitigating corrosion. It is impossible to cover adequately and properly in this short space the subject of marine corrosion of steel piling.

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