Part 4

FACTORS AFFECTING THE LIFE OF COASTAL STRUCTURES

CHAPTER 17

LIFE OF STEEL SHEET PILE STRUCTURES IN ATLANTIC COASTAL STATES

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As a basis for more accurate estimates of the useful life of steel sheet piling, in 1936 the Beach Erosion Board, in cooperation with a number of District offices of the Corps of Engineers, began a survey of the rate of deterioration of steel sheet piling. The plan of operations was developed by and the first inspection was made under the supervision of Mr. Ralph F. Rhodes, Engineer of the Savannah District. Subsequent inspections were under the supervision of Mr. Jay V. Hall, Jr. and most of the compilation and analysis of data were done by Mr. C. W. Ross, both of the Beach Erosion Board staff. The Corps of Engineers is indebted to the many owners of structures who contributed to the study by permitting drilling and measurement of piling.

The survey included examination of ninety-four structures located along the Atlantic Coast of the United States and the Gulf coast of Florida. The structures were selected to include a variety of conditions of exposure and treatment. Most were exposed to normal sea water or sea water only moderately diluted with fresh water. A few were exposed to fresh water with only occasional intrusions of sea water.

Measurements were made of the thickness of the webs of 153 groups of piles. In most cases, each group comprised 5 piles having similar environment and three sets of measurements were made covering the period of approximately 10 years from 1936 to 1946. Where practicable, measurements were taken at several elevations on each pile to include both tidal and atmospheric exposures. The removal of piling from structures at two locations permitted measurements of the entire length of each pile to obtain data on rates of loss under water and in earth.

TYPES OF STRUCTURES INVESTIGATED

The piling groups studied are classified by type of structure as harbor bulkheads, beach bulkheads, and groins. Harbor bulkheads are found in wharves, piers, slips, and retaining walls, all of which are protected to some extent from wave action. Backfill generally protects one surface of the piling, but the top portion of the piles may be exposed to the atmosphere on both sides. The portion between the levels of high and low water is exposed to alternate wetting or drying. The third portion is always under water, and the lowest portion is buried in the harbor bottom. Beach bulkheads are located along the shore to protect the land from storm waves. Those located back of the high water line are not subject to frequent wetting, except by salt spray from waves. The backfill and the beach materials are usually sand, but occasionally consist of coarser materials. Groins are structures built along the beach generally normal to the shore line to retard littoral currents near the shore with a view to accumulating or retaining beach material in a specific area. Some part of the groin surface is normally subject to rapid movement of beach material caused primarily by wave action. The exposure of jetties is generally similar to that of groins. Several pile groups in jetties have been classified with and analyzed with those in groins.

LOCATIONS OF STRUCTURES

In order to have distinct differences in climatic conditions, structures were selected by regions northward from Point Pleasant, New Jersey, and southward from Wilmington, North Carolina. A number of groins located at Cape May and Cape May Point, New Jersey, were also observed during the investigation, but were not measured. As no suitable beach bulkheads or groins were found north of Long Island, New York, only harbor bulkheads were observed in New England.

The various locations at which steel sheet piling were measured or observed by States are as follows:

- Florida - Clearwater Beach, Tampa, Sarasota, Fort Myers, Miami, Miami Beach, Bakers Haulover, Hollywood Beach, Palm Beach, Fort Pierce and Jacksonville;
- Georgia - Savannah Beach;
- South Carolina - Charleston;
- North Carolina - Wilmington and Kure Beach;
- New Jersey - Cape May, Point Pleasant, Manasquan, Belmar, Deal, Sea Bright, Long Branch and Harrison;
- New York - Harlem River, Brooklyn, Queens, Long Island City, East River, Island Park, Roslyn, Glen Cove, Oyster Bay, Asharoken Beach, Shinnecock Canal, and Southampton;
- Connecticut - Greenwich, Stamford, Norwalk, Bridgeport, New Haven, Branford, Middletown and New London;
- Rhode Island - Point Judith and Newport;
- Massachusetts - New Bedford, Woods Hole, Boston, Chelsea, Charleston, Lynn and Salem;
- Maine - Portland.

MEASUREMENTS OF THICKNESS OF PILING

The thickness of the web of each pile was determined by 8 or 10 measurements at each inspection. Rust, paint, and scale were carefully cleaned from both surfaces of the web before the measurements were made. Where practicable, 10 measurements were made near the top of the pile by means of a large striding micrometer. Where it was impossible to use the striding micrometer, a 3/4-inch hole was drilled through the web and 8 equally spaced measurements were made around this hole with a small hub micrometer. Where there was backfill which could not be excavated, a small amount of the backfill material was removed through the hole, paper was forced into the cavity to form a lining and the inner surface of the steel was cleaned with special scrapers operated through the hole.

Where practicable, measurements were made of the thickness of sound metal in the web of each pile at four zones defined relative to tidal planes, namely approximately at mean low water, mean tide level, mean high water and above high tide. After the measurements were completed the holes were filled with soft iron or lead plugs. New holes several inches from the old holes were drilled for the measurements at subsequent inspections. Averages of measured thicknesses by groups for each inspection were tabulated, classified by zones relative to tidal planes. The tabulated values were usually averages of at least 40 measurements, as in general each group comprised 5 piles and 8 or 10 measurements were made of each pile in each zone. Data relating to geographical locations, date of installation, condition of piling when installed (new or used) and nominal thickness of piling were also tabulated, classified by type of structure.

OTHER DATA ASSEMBLED

Other data recorded as far as practícable in connection with the investigation were as follows:

a. Manufacturer
b. Section of piling
c. Copper content, if any
d. Distance from nearest breakers
e. Exposure to direct wave action
f. Estimated intensity of currents
g. Salinity (estimated average condition)
h. Pollution
i. Tidal range
j. Nature of adjacent materials
k. Type of capping, if any
l. Condition of paint at each inspection
m. Amount of rusting and pitting
n. Oil or grease scum
o. Marine life

However, data on the foregoing factors did not indicate that any one was of major importance in determining the durability of steel piling.

RELIABILITY OF MEASUREMENTS AND COMPUTED RATES OF LOSS

The web thickness of the piles was measured with micrometers reading to 0.001 inch. The micrometers were checked and adjusted frequently. Although the measurements were at times made under difficult conditions, the number of measurements is considered adequate to render the effects of random errors and pitting unimportant.

As the measurements were made by a number of inspectors, it is possible that the surfaces were not always cleaned to the same degree. However, it is unlikely that errors from this source are serious, as this type of error is compensating.

Since the second and third sets of measurements were made at holes drilled several inches from the old ones, an error was introduced in the computed rate of loss of steel in cases where the original web thickness was not uniform. The webs of most new piles are of nearly uniform thickness, but in certain types the thickness of the webs increases from the center towards the edge. In known cases of these latter types, the new holes were drilled either vertically above or below the old holes. However, there are certain groups in which the change in thickness was less noticeable and in a few cases an increase in measured thickness resulted, presumably because of the change in the location of the holes.

The nominal thickness, as well as the measurements of the webs, was generally used in computing changes in thickness. Variations in thickness of new piling result from wear or lack of adjustment of the rollers. A weight tolerance of $2\frac{1}{2}$ per cent either way from listed weights is standard permissible mill variation. The first measurements were frequently greater than the nominal thickness by more than $2\frac{1}{2}$ per cent, indicating that the mills tended to produce piles which were overthick. When the web thickness determined from the first measurements exceeded the nominal thickness, the former has been taken as the initial thickness in computing losses.

The effect of errors in the determination of the thickness on the annual rate of loss decreases with time. The error of the rate of loss is probably seldom larger than 0.002 inch per year.

The computed losses of thickness are losses from all causes. The two causes which are believed to be principally responsible are: (a) corrosion, defined herein as loss due to chemical reaction with the environment, and (b) abrasion, loss due to wearing away by friction of moving materials. The latter appears to be an important factor in the case of groins, although the removal of rust and exposure of bare steel by abrasion may accelerate the corrosive processes.

PRINCIPAL FACTORS AFFECTING THE RATE OF DETERIORATION

All data assembled in connection with the investigation, as mentioned previously, have been considered to determine their significance relative to the rate of deterioration of piling. The number of variables considered which may have an effect on the rate of loss of steel is so large that even the number of measurements made in this survey is inadequate to cover all conditions thoroughly. Data secured appeared adequate to warrant general conclusions by comparison of rates only under the following categories:

a. Type of structure
b. Geographical locations
c. Zone relative to tidal planes
d. Sand, earth or other cover
e. Exposure to salt spray
f. Paint protection

Comparison of rates of loss in the several categories gave the following results.

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TYPE OF STRUCTURE - Based on all measurements the average rate of loss of thickness for harbor bulkheads was 0.0033 inch per year. By comparison the average rates for beach bulkheads, groins and jetties were 0.016 inch per year, indicating a durability of steel sheet piling in harbor bulkheads about 5 times that in other shore structures.

Observation of perforation of groins at Cape May and Cape May Point, New Jersey, provided additional data on rates of loss. All of these groins were built of piling having nominal web and flange thicknesses of 0.281 and 0.250 inch respectively. Some holes were observed after 4 years, indicating a maximum annual rate of loss of about 0.06 or 0.07 inch. The average time in which holes first appeared was about 7 years, indicating a rate of loss of about 0.04 inch per year. As may have been expected, the rates indicated by these observations are larger than average rates derived from measured holes, since the perforations naturally occur at points of worst exposure. Natural holes observed in measured piling provide examples of similar rates of loss. A previous study of deterioration of steel piling in groins at Palm Beach, Florida, revealed perforations with rates of loss from 0.04 to 0.09 inch per year.

GEOGRAPHICAL LOCATION - The average rates of loss of thickness for northern and southern regions for the three types of structures were as follows:

Region	Harbor Bulkheads Inch/year	Beach Bulkheads Inch/year	Groins and Jetties Inch/year
Southern	0.0062	0.017	0.018
Northern	0.0023	0.0075	0.011

Comparison of these rates indicates a durability of steel piling in the Northern Region averaging about double that in the Southern Region. However, the number of measurements of groin piling in the Northern Region was relatively small. Observations of natural perforations in unmeasured piles in New Jersey indicate high rates of loss, similar to those experienced in the South. A general conclusion that steel piling in groins has materially greater durability in the North than in the South appears to be unwarranted.

ZONE RELATIVE TO TIDAL PLANES - The average rates of loss of thickness for the several zones relative to tidal planes were as follows:

Zone	Harbor Bulkheads Inch/year	Beach Bulkheads Inch/year	Groins and Jetties Inch/year
8' above MHW	0.0049	0.020	0.010
5' to 8' above MHW		0.022	
2' to 5' above MHW		0.0081	

Mean high water	0.0027	0.0074	0.0055
Mean tide level	0.0024	0.001	0.024
Mean low water	0.0035	0.002	0.028

Comparison of rates for harbor bulkheads indicates little difference in the tidal zone from mean low water to mean high water. Above mean high water a rate about 70 per cent greater than the average rate in the tidal zone is indicated. For beach bulkheads, the rates for the area more than 5 feet above mean high water were somewhat more than double the rates for the area between, and 5 feet above, mean high water. In each of the two locations where piling was measured below mean high water, sand covered the zone at least part of the time and the rates of loss were negligible. For groins and jetties, rates for areas at and above mean high water averaged about one-third of the rates for the areas exposed to tidal and wave action.

Measurements of pulled steel piling provide data on deterioration by zones below mean low water. From mean low water to the ground line, the zone continuously submerged, the rate of loss averaged 0.0035 inch per year, the highest rates being within a few feet below the mean low water line. In the Miami groups lesser peaks in the rate also appeared just above the ground line. Below the ground line the average rate of loss was slightly under 0.002 inch per year.

SAND, EARTH OR OTHER COVER - The average rates of loss of thickness for several conditions of cover were as follows:

Cover	Harbor Bulkheads Inch/year	Beach Bulkheads Inch/year	Groins and Jetties Inch/year
No cover on either surface of pile	0.0075	0.027	0.019
One surface never covered, other covered part time	0.0076	0.020	0.014
One surface only covered	0.0026	0.0094	0.020
One surface always covered, other covered part time		0.0065	0.0057
Both surfaces covered part time			0.017
Both surfaces always covered		0.0017	0.0026

Comparison of rates for harbor bulkheads indicates that lack of backfill for all or part of the time greatly increases the rate of loss. For beach bulkheads the rate of loss rapidly decreased as the cover increased. For groins and jetties the rates of loss were uniformly high except for those covered on both sides all or part of the time.

EXPOSURE TO SALT SPRAY - The average rates of loss of thickness of harbor bulkheads for heavy, moderate and light salt spray were respectively 0.0083, 0.0041, and 0.0024 inch per year. All beach bulkheads, groins and jetties are considered to be subject to heavy spray. The average rate of loss for these structures was 0.016 inch per year. You will note the much higher rates of loss where piling is subject to salt spray.

PAINT PROTECTION - The average rates of loss of thickness without painting and with painting on one or more occasions were as follows:

Painting	Harbor Bulkheads Inch/year	Beach Bulkheads Inch/year	Groins and Jetties Inch/year
None	0.0045	0.018	0.020
At least once	0.0027	0.011	0.010

Comparison indicates a substantially lower rate of loss for structures that had been painted at least once. Data on composition of paints and the manner of application were too limited to permit study of these factors. Few of the structures studied were painted regularly. The fact that occasional painting reduced the rate of loss substantially indicates that regular painting would result in greater reduction. Determination of the economic justification of regular painting would require study of painting costs. As rates of loss for beach bulkheads are high and as painting of these structures is less costly than complete painting of harbor bulkheads, regular painting of beach bulkheads may be justified. The same is true of the zone above mean high water of harbor bulkheads. Painting of groins and jetties in the tidal zone, subject to abrasive action, probably could not be justified.

CONCLUSIONS

The mean rate of loss of thickness of steel sheet piling based on a total of 451 weighted averages was about 0.008 inch per year. The rates of loss vary materially under different environmental conditions. Consequently, different types of structures and the several portions of the same structure have different rates of loss. In addition to specific rates of loss under various conditions, just discussed, the data are adequate to warrant the following general conclusions:

a. The rates of loss are much lower for harbor bulkheads than for other shore structures studied;

b. The rates of loss for harbor and beach bulkheads are lower in northern than in southern States;

c. The rates of loss for harbor and beach bulkheads are materially higher for surfaces above mean high water than for surfaces within the tidal range. The rates of loss for groins and jetties are much greater at mean tide and mean low water levels than at higher elevations;

d. Sand or earth cover materially decreases the rate of loss, the rates of loss for all practical purposes being negligible for piling always covered on both sides;

e. Exposure to salt spray greatly increases the rate of loss;

f. Painting, either initially or at irregular intervals, materially reduces the rate of loss.

The useful life of steel sheet pile structures depends on the original thickness of the steel, the rate of loss of thickness, and the thickness of the piling when the structure is no longer useful because of loss of thickness. The data obtained will enable the designer to estimate the probable life of a structure, giving due consideration to environmental factors, and to determine the justification of protective coverings such as paint, concrete or wood sheathing to reduce the rate of loss in the more vulnerable portions of the structure.