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EXPERIMENTAL STEEL PILE GROINS, PALM BEACH, FLORIDA

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DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

EXPERIMENTAL STEEL PILE GROINS PALM BEACH, FLORIDA

TECHNICAL MEMORANDUM NO. 10

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FOREWORD

This report is the result of cooperative effort between the Beach Erosion Board and the Jacksonville District, Corps of Engineers. The text was prepared by the staff of the Engineering and Research Branch, Beach Erosion Board. The analysis and reduction of data was done by Culbertson W. Ross.

Acknowledgment is made to the many who contributed in the collection of data over a period of years; to the donors of the piling, the Inland Steel Company; Carnegie-Illinois Steel Corporation; Bethlehem Steel Company; Jones and Laughlin Steel Corporation; Larssen Company and to the donors of protective coatings.

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1. This report describes the results of a field test of five steel sheet pile groins constructed on the Atlantic Coast at Palm Beach, Florida. The location of the groins is shown on Figure 1. The steel sheet piling in the groins was donated for research purposes by the Carnegie, Bethlehem, Jones and Laughlin, and Inland Steel Companies of the United States and the Larssen Company of Germany. An interim report on the test was prepared 11 May 1944.

2. The test program was initiated by the Beach Erosion Board to determine the reasons for the rapid deterioration of steel sheet piling at Palm Beach, Florida, and to test certain methods of preventing deterioration. Designs were furnished by the Beach Erosion Board and the groins were built by the City of Palm Beach during January through April 1937. Between that date and 1946 the groins were inspected 40 times. The report of each inspection covered the condition of the groins and the factors of their environment which might affect their useful life. Web thickness of typical individual piles of each groin was measured in 1940, 1942, and 1946.

PHYSICAL FACTORS AFFECTING LIFE OF GROINS

3. Winds. Wind records furnished by the U. S. Weather Bureau for West Palm Beach covering the 1938 through 1946 period indicate that wind velocities were greater from the northeast sector than from the southeast sector, but that duration and wind movement were greater from the southeast sector than from the northeast sector. Southerly winds occur usually in the spring and summer months. Study of winds in offshore areas in U. S. Hydrographic records covering the 1879-1933 period indicates that the strongest winds are from the northern and eastern sectors.

4. Tides. The mean range of tide in the Atlantic Ocean at Palm Beach is 2.8 feet; the spring range is 3.3 feet. The lowest tide to be expected is 2 feet below mean low water. Variations of more than 7 feet in water surface elevations have resulted from storms.

5. Storms. The general area is subjected to occasional tropical cyclones of hurricane intensity. Two such storms occurred during the test period of the experimental groins, in 1941 and 1944.

6. Beach Material. Samples of beach material were collected in the vicinity of the experimental groins at Palm Beach. Analysis of the material indicated that the median diameter is 0.5 millimeters, the specific gravity 2.70 and the shell content about 64 per cent. After leaching it was found that the remaining material was practically pure quartz. Micro-photographs of typical material are shown on Figures 2 and 3. According to Russell's classification the quartz is sub-angular.

7. Littoral Drift. In 1928, 320-foot jetties were built to improve Lake Worth Inlet. Since their construction sand has accumulated north of the north jetty and the beaches south of the inlet have been depleted of sand. The prevailing summer winds, usually moderate, create waves which cause drift from south to north and tend to build up the beaches on the south side of the inlet. This tendency is offset, however, by the rapid movement of beach material from north to south caused by the violent wave action produced by winds from the northeast the prevailing direction in winter. Hence, there is a reversal of drift in this area but the predominant littoral drift is from north to south. An effect of the direction of the littoral drift may be noted in Table I, which gives the position of the -1 foot mean low water contour on each side of the groins at 39 inspections. This point is usually farther out from the shore on the south side of the groins during the summer when the drift is from the south.

8. Site of Groins. The experimental groins were built along a segment of the beach immediately south of the south jetty at Lake Worth Inlet in an area where the depletion of sand was pronounced and it was believed that there was danger that the barrier beach might be breached. The groins apparently prevented further loss of sand, but little if any, accretion occurred. As a result, the groins, over most of their lengths, were exposed to wave action, scouring sand, spray, sun and air from 1937 through 1944. Groin 139-N was more protected than the others by accumulated sand.

9. Supply of Artificial Material. The continued deterioration of the beaches below Lake Worth Inlet necessitated remedial measures to prevent possible failure of protective bulkheads. To protect the bulkheads and restore the beaches, 280,000 cubic yards of sand were pumped from Lake Worth to the beach near Groin 139-N in the summer of 1944. That groin was completely covered by sand and the action of the waves and littoral currents on the artificial supply of sand built up the beach adjacent to the other experimental groins. The addition of the material interrupted the sequence of natural events in the vicinity of the groins and undoubtedly seriously affected the corrosion rate of the steel. This factor was accounted for in the analysis of the data by correlating the position of the sand line with the location of the measurement area.

DESCRIPTION OF GROINS

10. Details of the five groins are shown on Figures 4 through 8. Four of the groins are built from standard structural rim steel, containing less than 0.05 per cent copper. The fifth, groin 112-N, was built with steel piles containing 0.35 per cent copper. A chemical analysis of the steel from one pile of each type is given in Appendix 2. The location of the five types of piles used in the groins is shown in Figures 4 to 8. The steel piles are designated by type numbers representing the individual companies supplying the product. In addition to the greater amount of copper, the thickness of the piles in groin 112-N was much greater, being 0.547 inches for groin 112-N, as compared with 0.375 inches for the other groins (see Table II). Some of the groins are supported by round, timber piles and timber wales which were treated by the vacuum-and-pressure process using 16 pounds of creosote per cubic

foot of wood. Field cuts were also brush-treated with creosote during construction. A number of the piles in Groin 139-N were covered initially with various commercial and government specified coatings as designated by letters on Figure 4. All piles in Groin 112-N were covered initially with a coating of commercial shop paint. The formulas for the government specified coatings are given in Appendix 1. Groin 121-N was sheathed with 2-inch creosoted timber planking for 65 feet of its length, from 12 feet to 77 feet from the bulkhead.

NOMENCLATURE

11. The original measurements of web thickness in 1940 were made at holes drilled in three specific areas along the groins as shown on Figures 4 - 8 and the rates of loss of steel from the web of the piles studied are illustrated on Figure 9 and are defined as follows:

a. The air corrosion zone is the groin surface generally subjected to air and spray except during storms.

b. The sand protected zone is that part of the groin surface 0.2 foot or more below the beach surface.

c. The abrasion zone is that part of the groin surface subjected to the rapid movement of beach material caused primarily by wave action. The limits of this zone are taken arbitrarily as points 0.2 foot below and 0.6 foot above the sand line.

d. The wetting and drying zone is that part of the groin surface subjected periodically to immersion in sea water, and is defined roughly as that portion of the groin between mean low water and mean high water. Fluctuations in the beach profile immediately adjacent to the groins caused such rapid changes in the position of the sand line relative to the drilled holes as to change frequently the type of exposure in the three areas. Consequently the drilled holes in Area 1 were at times in the air corrosion zone and at other times in the sand protected zone. For the same reason the drilled holes in Area 2 and 3 were at times in the sand protected zone, the abrasion zone or the wetting and drying zone depending, of course, on the position of the sand line.

OBSERVATIONS

12. Intermittent reports on groin and beach conditions covered the general appearance of the groins, the condition of the protective coatings, the profile of the beach parallel to and one-foot on each side of every groin, and other information such as the condition of the supporting piles, timber wales and sheathing. The most significant notes in the reports for each groin follow in chronological sequence.

a. Groin 139-N - Completed March 1937

May 1937. All coatings have disappeared from a narrow zone above the sand line. Rust is observed through paint E above the abrasion zone. Coating A appears to be in good condition except in the abrasion zone.

July 1937. A few patches of coating E remain on the exposed surface of the piles; about 95 per cent of the coatings A, B, C, and D are gone.

May 1941. For the first time, holes are observed in the piles at the sand line in the interval between 90 and 110 feet seaward of the bulkhead. See Figure 4. Traces of commercial coatings V, W, and X are still evident on the exposed groin surfaces, but the other coatings have disappeared completely.

June 1942. Holes are observed in the piles in the interval between 90 and 130 feet seaward of the bulkhead.

May 1944. Holes as large as 6 by 12 inches are observed in the piles in the interval between 50 and 90 feet seaward of the bulkhead. In the interval 90 to 135 feet seaward of the bulkhead, the webs and flanges have been worn away from about 2 feet above the sand line, leaving the wales supported only by the interlocks. The outer 16 feet of the south wale is gone.

July 1946. All except the outer 12 feet of the groin is covered with sand which originated from the artificial supply pumped on the beach; that portion projects about 14 inches above the sand.

b. Groin 135-N - Completed March 1937

June 1937. The steel piles are covered with rust except in the area immediately adjacent to the sand line where the rust has been cut away.

May 1941. For the first time, holes are observed at the sand line in the piles between 90 and 110 feet from the bulkhead. See Figure 5.

January 1943. The seaward 74 feet of wales are gone and the next 60 feet are in poor condition. All supporting piles remain standing but appear badly worm eaten.

May 1944. Holes are in the piles in the interval 60 to 70 feet from the bulkhead; the web and flanges are almost completely worn away in the interval 70 to 125 feet from the bulkhead for about 2 feet above the sand line.

July 1946. The wales are gone from the seaward 130 feet of the groin and the four supporting piles at the outer end of the groin have been cut off below the water line by marine borers. Sand which was pumped on the beach now covers most of the openings in the piles.

c. Groin 131-N - Completed February 1937

December 1939. Twenty feet of the south wale at the outer end of the groin is gone.

November 1940. The wales are gone from the outer 64 feet of the groin; most of them were in place in August 1940.

December 1941. For the first time holes are observed in the piles at the sand line in the interval between 81 and 92 feet from the bulkhead. See Figure 6. The outer 74 feet of wales are gone.

May 1944. Holes are in the piles at and above the sand line in the interval between 81 and 95 feet from the bulkhead. The outer 107 feet of the south wale and 98 feet of the north wale are gone.

July 1946. The outer 120 feet of wales are gone and the supporting piles for the outer 20 feet of groin are gone also.

d. Groin 121-N - Completed March 1937

June 1937. The creosote color has faded from the supporting timber piles and wales.

February 1941. The wooden sheathing appears badly deteriorated.

May 1944. Very little timber sheathing remains on the groin beyond 65 feet from the bulkhead.

March 1946. The timber sheathing is gone beyond 65 feet from the bulkhead. Holes appear in the piling in the interval between 77 and 83 feet from the bulkhead. See Figure 7.

July 1946. The outer 30 feet of wales are gone. A hole in the pile is observed at 68 feet from the bulkhead.

e. Groin 112-N - Completed March 1937

November 1937. A strip of bright metal about 8 inches wide is observed at the sand line.

August 1940. Traces of the original coating are evident on the upper part of the piles near the bulkhead.

July 1946. No holes have been found in the piles.

April 1948. The groin was examined again and numerous holes were found in the groin from the 45th pile to the 62nd pile. The elevation of the holes varied from +1.6 feet mean low water at the 45th pile to +0.7 feet mean low water at the 62nd pile.

f. All Groins.

Most of the inspections indicated that there was a minimum of rust on the piles at the sand line; some of the inspections revealed that the metal was polished brightly for several inches above the sand line. It was observed that most of the piles except those rarely exposed to sea water were covered usually with very heavy growths of marine life, the most conspicuous being sabelleria and barnacles. Typical photographs showing the condition of the groins at various times during the field test are shown on Figures 10 and 11.

13. Beach Profiles Adjacent to Groins. At each inspection, profiles of the beach were obtained from elevations taken at 10-foot intervals along a line parallel to and one-foot away from both sides of the five groins. A high profile on one side of a particular groin was usually accompanied by a low one on the other. The measured sand elevations varied, the variation being about 6 feet near the bulkhead and decreasing to about 2 feet in the deeper water 100 to 150 feet seaward. The one-foot contour below mean low water was selected as an index of the fluctuation of sand elevation with respect to the groin, because at that elevation a break in the beach profile usually was observed, the beach was steeper shoreward of that point and the area of serious abrasion extended from that point shoreward. The extent of these variations is indicated in Table I which gives the distance from the bulkhead at which the elevation of the beach adjacent to the groins was at the minus one-foot contour, together with the date of survey.

14. Method of Measurement. The rate of reduction in thickness of steel was determined by measuring the web of selected piles in each groin periodically and comparing the average measurement obtained. In most instances five piles in each of the three areas shown on Figures 4 - 8 were measured during August 1940, June 1942, and June 1946. The rust and scale were removed by striking with a hammer and the remainder of the rust was brushed from the pile surfaces with a flexible wire brush. Then, a 3/4-inch hole was drilled through the web and a small hub micrometer was used to take eight readings around the circumference of each hole, thus obtaining an average measurement. Upon completion of a set of measurements, the holes were plugged with soft iron or lead. Subsequent measurements were made at new holes drilled in the same pile several inches from the old ones.

15. Measured Rate of Reduction in Thickness. Table 2 summarizes the results of the three sets of measurements giving the groin number, the location of the center of each set of holes where measurements were made, the nominal thickness of the steel, the average thickness for each set of measurements, and the rate of change in web thickness for each period and for the entire period covered by the experiment.

16. Average Annual Rate of Reduction in Thickness of Naturally Perforated Areas. Holes appeared by natural deterioration in all of the groins built from the 0.375-inch steel piling. The average annual rates of reduction of thickness of the steel were determined from observation of the time of appearance of the first holes in the piles and considering the elapsed time between the installation of the groin and the date of the observation. Groin 121-N (Figure 7) was protected over 75 feet of its length by 2-inch, treated timber sheathing. Groin 112-N

(Figure 8) built of 0.547-inch steel had no holes up to March 1946 although holes were observed in April 1948. The dates when holes were first observed in the groins, the time elapsed, the approximate location of the center of the naturally perforated area, the number of years elapsed from installation until the holes were first observed and the annual reduction in web thickness of the steel on this basis are given in the lower portion of Table 2.

17. Protective Coatings. The commercial and government specified coatings used on Groins 139-N (Figure 4) and 112-N (Figure 8) disappeared from the exposed portion of the piles for all practical purposes in less than six months.

18. Wood Sheathing. The creosoted wood sheathing protecting Groin 121-N is shown on Figure 7. Three planks removed from the north side of the groin in order to measure the web thickness in August 1940 were not replaced. The sheathing did not afford complete protection to the piles because beach material was introduced into the space between the sheathing and the piles from the top of the groin by breaking waves. The smaller material, such as sand and shell, promptly washed out; but the stones and larger detritus remained to be agitated by water jetted through the spaces between the individual planks in the sheathing by wave action, thereby subjecting both the steel and the timber to wear from this source. The condition of the sheathing in August 1940 is shown on the upper photograph of Figure 12. The wood sheathing apparently protected the steel piling effectively over the first 5 years, after which it deteriorated rather rapidly. As shown by the lower photograph of Figure 12, by June 1946 the sheathing had become completely ineffective and all that remained were knife-edged stalagmite-shaped pieces of wood which projected above the sand line.

DISCUSSION

19. The purpose of the field test of the five experimental groins at Palm Beach, Florida, is to determine the life expectancy of steel sheet piling in such semi-tropical waters and in an area where there is a considerable movement of beach material. The effects of certain coatings and wood sheathing in preserving the piling are included as a part of the field test. The life of the piling is naturally dependent on the physical factors of the environment. The effects of these factors are manifested by the disappearance of the protective coatings from the pile surface, the deterioration of the protective sheathing, and the deterioration of the piles as evidenced by the reduction in thickness of the steel.

20. Accuracy of Measurements. The thickness of the piles was determined from the average of eight readings made at each drilled hole, and there were usually five such holes or a total of forty measurements. Each measurement was made to the nearest 0.001 of an inch. The web thickness of the piles was not measured before the groins were built; hence, there is no authentic check on the nominal thickness used in determining the rate of reduction in thickness of

the web. However, most steel catalogues specify weight tolerance for rolled piles as 2½ per cent; the nominal thickness should, therefore, not vary by more than this amount. On this basis, assuming uniform density, the pile thickness could vary by as much as 0.009 inch from the nominal value.

21. Variations in the web thickness of the pile probably introduced discrepancies in the basic data as is manifested by the apparent increase in thickness of a few of the measurements. The measurements further indicate that the steel corrodes at an irregular rate, the extreme example of which is pitting, but the number of readings should reduce the effect of random changes in the rate of reduction in thickness. Pitting could also result in an apparent increase in pile thickness with time, if a group of holes or an individual hole drilled in a pitted area for one set of measurements were compared with a subsequent set of measurements from a hole drilled in a relatively unpitted area. The effect of errors in the measurements on the rate of reduction in the thickness of the steel decreases with time; the longest period, therefore, gives the most accurate measure of that rate.

22. <u>Exposure of the Measured Areas</u>. The exposures of the measured areas were determined from the thirty-nine surveys in which profiles were obtained parallel to and one-foot on both sides of each groin. There were 21 surveys made prior to the first set of measurements in August 1940, 7 additional surveys prior to the second set of measurements in June 1942, and 11 surveys prior to the last set of measurements in June 1946. Obviously the profiles thus obtained do not afford an exact determination of the exposure of the measured areas because of the rapidity with which the beach profile changes during storms and the few surveys made for the time period involved. Nevertheless, in an attempt to correlate the rate of reduction in thickness of the piles with the position of the sand line, i.e., determine that rate for the four significant zones selected, it was assumed that each profile was representative of the interim between surveys. Predicated on the above, the percentage of time that the approximate center of each measurement area was in the air corrosion, sand protected, abrasion or wetting and drying zones is given in Table 3. The data covers all periods between the installations of the groins and each measurement and the entire period.

23. <u>Significance of the Natural Holes</u>. The naturally formed holes which were observed at or near the sand line of all groins built from 0.375 inch piles afford another measure of the loss of steel from the piles at the area which obviously has been subjected to the greatest wear for the longest period. The appearance of these naturally formed holes signifies the termination of the life of the groins as impermeable structures. A correlation between the positions of the sand line in the immediate area of the holes affords another measure of the reduction in web-thickness of the steel for the sand-covered, abrasion and wetting and drying zones; their position near mean low water excluded them from the air corrosion zone. The types of exposure of these naturally perforated areas based on all surveys prior to the date the holes were first observed are also given in Table 3.

which the natural holes appeared were obviously points which were subjected to maximum abrasion. These points appeared to be at locations where the turbulence of the breaking waves was probably most pronounced and prolonged; however, no observations were made of the location of the breaker line and the breaker zone which would permit a definite statement of this condition.

28. Evaluation of the Rate of Reduction in Thickness. The annual rates of reduction in thickness of the steel for the four zones should be considered as approximate rather than exact indications of the behavior of the steel in the groins. The accuracy of the computed rates for the four zones naturally depends on the accuracy of the measurements. The error of individual measurements was probably seldom greater than 0.001 inch, however, variations in the original web thickness and variations in the web from one point to another introduce larger uncertainties in the measured pile thickness. A larger number of profiles to establish more exactly the exposures of the groin surfaces would have been desirable. Unfortunately, World War II interrupted the periodic inspections and their number diminished with successive time intervals. The possibility of a very high rate of loss of thickness is confirmed by the appearance of large holes in 1.7 years in another groin built in the same area from 0.375-inch piles.

29. Type of Piles. The observations reveal that the groins built from straight section piles resisted perforation for about 9 months longer than did those built of arch section piles. Perhaps this was due to the arch section piles obstructing the sand movement more than did the straight section ones, which action may have subjected the arch piles to more wear from the moving beach material.

30. Groin 112-N remained unperforated at the last regular inspection in 1946, though perforations were evident in April 1948. The greater length of time required for perforation of this groin may be explained by the much greater thickness of the steel in the piles composing the groin, 0.547 inches instead of 0.375 inches (see Table 2). The steel used in this groin also contained 0.35 per cent copper which may have been a factor in increasing the time required for perforation; however, very high rates of loss of thickness were found at some of the points measured in this groin (see Table 2) which indicates that the greater thickness of the steel and not the higher copper content was probably the chief factor in increasing the resistance to perforation.

31. Rim steel, from which the piles of these experimental groins were made, is reportedly harder at the surface than at the center of the section because of the pressure of the rolls used in forming the piles. It is thought that this variation in hardness may cause an increase in the rate of loss of thickness with time as the softer material is exposed. However, the accuracy of the rate of corrosion as determined by the loss of thickness between inspections is not great enough to determine whether such an increase in rate of corrosion prevails or not.

24. Computation Procedure. Since the drilled holes (Area 1) nearest the bulkhead alternated between the air corrosion and sand protected zones (see Table 3), the rate of reduction in thickness of the piles may be expressed in an equation of the type,

$$ax + by = c \qquad (1)$$

in which a is the per cent of time that the area was exposed to the atmosphere, and x is the rate of reduction in thickness for that type exposure; b is the per cent of time which the drilled area is covered by sand, and y is the average rate of reduction in thickness for that condition. Finally c is the average rate of reduction in thickness per year. The solution for all groins for the three periods involves 15 separate equations of the above type. The probable values for the rates of reduction in thickness were determined by the method of least squares. This method, of course, gives a definite answer, although it is not necessarily the correct answer. The accuracy of the rates of reduction in thickness thus determined, naturally depends on the degree to which the thickness measurements are accurate and the degree to which the limited number of observations of the position of the sand line relative to the exposure area are representative. By this method, the computed rate of reduction in thickness for the sand protected zone of the groin is 0.001 inch per year and that for the air corrosion zone 0.011 inch per year.

25. The drilled holes in Areas 2 and 3 were at times in the sand protected, abrasion, and wetting and drying zones. Omitting the data from those piles protected by timber sheathing and for those piles covered with a protective coating during the first period, the problem resolves into the solution of 24 equations of the same type as Equation 1 except with three unknowns. The solution of 5 of these equations which show a 100 per cent exposure in the wetting and drying zone give an average rate of reduction in thickness for such pile surface of 0.005 inch annually. Substituting this value and the measured average rate of reduction in thickness of the drilled areas in the remaining equations, together with the previously evaluated loss in the sand protected zone of 0.001 inch annually, the computed average rate of reduction in thickness for the abrasion zone is found to be 0.117 inch per year.

26. The rate of corrosion of 0.117 inch per year determined in the preceding paragraph was based entirely on micrometer measurements at the drilled holes. A similar calculation can be made based on the appearance of natural holes in groins 139-N, 135-N, and 131-N. Such a computation is possible after the rates of 0.001 and 0.005, respectively, for the sand protected and the wetting and drying zones have been established. On this basis the computed average rate of reduction in thickness in the abrasion zone is 0.373 inch annually. Groin 121-N is not included in this computation because it was protected by timber sheathing.

27. The variation of the values for the rate of reduction in thickness for the abrasion zone as indicated by the two methods employed in paragraphs 25 and 26 is to be expected, as the points at

CONCLUSIONS

32. The location of the naturally perforated holes in the piling, the thinness of rust and frequent appearance of bright polished metal at the sand line shows that the beach material moving under wave action is the primary factor in the rapid deterioration of steel piling at Palm Beach. The principal wear on the piles occurs in a zone a few inches above and below the sand line. Abrasion by the sand continually removes the rust covering and re-exposes the bare steel to oxidation, thereby accelerating corrosion. The moving sand may also abrade the steel. Based on visual observation at the site of the experimental groins, the zone of rapid abrasion appears to be usually an inch or so wide and extends from near the upper limit of wave uprush seaward to depths greater than one foot below mean low water. Its position changes frequently as the sand line adjacent to the groin fluctuates. In order to take into account these fluctuations, the abrasion zone was arbitrarily taken as extending from 0.2 foot below the sand line to 0.6 foot above as shown in Figure 9.

33. The most significant measure of the life of the groin is the rate of reduction of thickness of the piles in the abrasion zone. The rate in that zone, as indicated by the micrometer measurements, was 0.117 inch annually. The rate indicated by the appearance of natural holes was 0.373 inch a year. At the latter rate, if the abrasion zone did not shift, a groin built from 0.375 inch piles could be perforated in about one year. Obviously the holes appeared first at points of maximum abrasion. These points where natural holes first appeared seem to have been located where the turbulence of the breaking waves was probably most pronounced and prolonged. This would account for the higher rate of corrosion in the abrasion zone indicated by the initial appearance of these natural holes at points in the surf zone where it was impractical to obtain micrometer measurements at the periodic inspections.

34. The results of the field test show, rather conclusively, that the loss of steel from those pile surfaces in the other three zones shown in Figure 9 is much less than in the abrasion zone. The degree is indicated by the computed average annual rate of 0.011 inch for the air corrosion zone, 0.005 inch for the wetting and drying zone, and 0.001 inch for the sand protected zone.

35. The rate of reduction in thickness of 0.001 inch for the sand protected zone suggests that an abundant supply of sand which would practically cover the groins would prolong their life for a considerable period. It is recognized, of course, that groins are seldom built except at locations where more sand is desired and that a groin in performing its function of holding or accumulating sand will be exposed, at least in part, to waves and sand erosion.

36. The test shows definitely that the protective coatings used on some of the piles are ineffective in preventing abrasion of the groin surface or in protecting any exposed portion of the groins for more than 6 months.

37. The two-inch treated timber sheathing placed over the groin surface in the abrasion zone may prolong the life of the groins in the locality for the effective life of the timber, in this case about 5 years.

38. The steel used in the groin construction was furnished by five different manufacturers. An analysis of samples of the five steels showed them to be basically similar except that Type 5 (Groin 112) was a copper-bearing steel whereas the others were not. A comparative analysis of the yearly loss in thickness as determined from micrometer measurements (see Table 2) indicates no superiority of the copper-bearing steel over ordinary steel for use in steel sheet pile groins.

39. The groins built from the arch section 0.375 inch steel piling were perforated in less than 4 years and in 7 years as much as 60 feet of a groin became useless for trapping sand. Straight section groins have somewhat longer life than do deep arch section groins of the same thickness, but holes were worn in straight section groins in less than 5 years, and in 7 years a considerable length of groin became useless as a sand barrier. Groins built from thicker sections of steel sheet piling may have a proportionately longer life sufficient to more than amortize the added cost of the heavier steel when compared with groins built with thinner section piles. Holes did not appear in the groin at Palm Beach built with 0.547 inch piling until after more than 9 years.

40. A better method of measuring the thickness of the piles and more frequent observations of the position of the sand line, and perhaps also of the position at which the waves were breaking, would have been desirable to improve the accuracy and reliability of this field test. It is felt, however, that the data presented in this paper should be of interest and value to those who are concerned with the durability of steel sheet pile groins. Since this study was started, a number of methods for the non-destructive measurements of steel thickness have been developed. Some of these might be applied to the measurement of the thickness of steel sheet piling with better results. The sonic method, however, which is the most used of the new methods, requires flat surfaces which are not present in corroded steel sheet piling.

41. The above conclusions are based on observations at Palm Beach, Florida. They should be of value in estimating the life of groins at other places but may be subject to some modification because of different circumstances of exposure.

TABLE I

Distance from Bulkhead to Minus One Foot Contour (MLW) on North and South Sides of Groins

Date of Inspection	139-N		135-N		131-N		121-N		112-N	
	N	S	N	S	N	S	N	S	N	S
5 May 1937	130	100	90	60	80	50	60	50	80	50
1 Jun 1937	110	100	80	70	70	60	50	40	60	50
7 Jul 1937	120	130	70	110	40	90	20	90	60	90
2 Aug 1937	120	120	90	110	30	90	30	90	30	80
7 Sep 1937	120	130	50	110	40	100	30	120	50	100
8 Oct 1937	130	130	90	90	70	100	80	90	80	50
4 Nov 1937	150	120	120	60	90	50	70	40	50	60
29 Apr 1938	90	110	80	70	60	60	50	50	40	50
30 Aug 1938	120	140	60	120	50	90	30	80	20	70
21 Oct 1938	130	110	110	100	80	40	50	40	70	40
3 Jan 1939	110	100	120	100	90	40	60	40	50	40
1 Apr 1939	150	150	130	140	40	120	40	100	30	90
20 May 1939	110	120	60	120	70	110	70	90	30	70
5 Jul 1939	100	120	80	120	40	90	40	90	20	70
14 Aug 1939	110	130	80	120	50	150	60	100	20	100
19 Sep 1939	110	100	80	80	80	80	80	70	40	60
23 Oct 1939	150	140	90	60	80	40	80	30	70	40
7 Dec 1939	150	150	120	110	100	50	80	40	70	40
13 Feb 1940	110	120	90	110	80	80	60	40	50	50
15 Apr 1940	150	100	110	80	90	50	90	40	60	40
21 Jun 1940	90	140	80	120	60	120	50	100	20	80
21 Aug 1940	90	110	70	90	60	90	60	70	30	70
27 Nov 1940	130	120	110	110	100	100	60	80	60	70
14 Feb 1941	140	110	130	120	120	90	90	60	80	70
12 May 1941	100	110	80	100	60	100	80	70	50	70
29 Sep 1941	110	140	90	100	80	90	80	100	50	70
26 Dec 1941	110	120	90	110	80	80	60	100	50	80
21 Apr 1942	100	100	100	90	90	120	100	80	60	50
19 Jun 1942	110	130	100	100	90	90	100	130	50	80
19 Oct 1942	160	140	150	110	130	80	100	90	100	140
15 Jan 1943	120	110	100	90	80	80	100	80	60	50
29 Jun 1943	120	120	90	90	90	90	60	110	20	80
22 Jan 1944	110	110	90	90	90	90	110	100	80	40
16 May 1944	120	110	80	70	80	70	90	80	70	40
10 Jul 1944	100	90	80	80	80	80	80	110	50	70
11 Oct 1944	200+	200+	200+	200+	90	130	70	110	50	80
11 May 1945	170	170	140	140	110	130	90	110	40	80
19 Mar 1946	190	190	120	140	100	130	110	110	50	90
2 Jul 1946	150	150	110	120	90	100	100	120	50	90

TABLE II

MEASURED REDUCTION IN WEB THICKNESS IN EXPERIMENTAL STEEL SHEET PILE GROINS AT PALM BEACH, FLORIDA

DRILLED AREAS

Groin No.	Coordinates of Measurements: Dist. of Center of Group from Bulkhead (Feet)	Coordinates of Measurements: Elevation (MLW)	Nominal Web Thickness (Inches)	Average Measured Thickness (Inches) 1940	1942	1946	Annual Reduction in Web Thickness (Inches) 1937-40	1940-42	1942-46	1937-46
139-N	26	5.7	.375	.322	.312	.308	.015	.005	.001	.007
135-N	23	5.7	.375	.317	.305	.284	.017	.006	.005	.010
131-N	22	5.7	.375	.341	.351	.347	.010	.005+	.001	.003
121-N	9	5.7	.375	.340	.338	.348	.010	.001	.002+	.003
112-N	7	4.9	.547	.517	.517	.513	.009	.000	.001	.003
139-N	67	1.2	.375	.334	.347	.333	.012	.007+	.003	.005
135-N	53	1.3	.375	.313	.314	.286	.018	.000	.007	.010
131-N	57	0.0	.375	.263	.227	.151	.033	.019	.019	.024
121-N	69	2.1	.375	.378(2)	.366(2)	.344(2)	.001+	.006	.008	.003
121-N	69	0.1	.375	.360(2)	.346(2)	.200(2)	.004	.007	.037	.019
112-N	58	0.4	.547	.479	.364	.272	.020	.061	.023	.030
139-N	136	0.1	.375	.344	.307	.345(1)	.009	.019	.004+	.003
135-N	145	1.5	.375	.354	.351	.295	.006	.001	.014	.009
131-N	87	1.7	.375	.358	.324	.278	.005	.017	.012	.010
121-N	111	1.5	.375	.357	.344	.322	.005	.007	.003	.004
112-N	89	0.6	.547	.548(1)	.528	.520(1)	.000	.010	.002	.003

(1) Only one pile measured
(2) Only two piles measured.

TABLE II (continued)

MEASURED REDUCTION IN WEB THICKNESS IN EXPERIMENTAL STEEL SHEET PILE GROINS AT PALM BEACH, FLORIDA
NATURALLY PERFORATED AREAS

Groin No.	Coordinates of Holes: Dist. of Center of Set from Bulkhead (Feet)	Coordinates of Holes: Elevation (MLW)	Nominal Web Thickness (Inches)	Date Holes Observed	Approximate Time (Years)	Annual Reduction in Web Thickness (Inches)
139-N	100	-0.8	.375	May 1941	4.2	.094
135-N	80	-0.5	.375	May 1941	4.2	.094
131-N	85	-0.5	.375	Dec 1941	4.8	.076
121-N	80	+0.4	.375	Mar 1946(3)	9.0	.042
112-N	47 - 65	+0.7 - 1.6	.547	Apr 1948	11.1	.049

(3) Groin Protected by 2-inch Wood Sheeting.

TABLE III

PERCENTAGE OF TIME DRILLED AND NATURALLY PERFORATED AREAS WERE SUBJECTED TO DIFFERENT EXPOSURE CONDITIONS

DRILLED AREA 1

PERIOD	1937-40		1940-42		1942-46		1937-46	
GROIN	Air Corrosion	Sand Protected	Air Corrosion	San Protected	Air Corrosion	Sand Protected	Air Corrosion	Sand Protected
139-N	51	49	18	82	23	77	31	69
135-N	61	39	32	68	44	56	47	53
131-N	75	25	74	26	54	46	65	35
121-N	61	39	22	78	14	86	31	69
112-N	51	49	50	50	44	56	48	52

DRILLED AREA 2

PERIOD	1937-40			1940-42			1942-46			1937-46		
GROIN	Sand Protected	Abrasion	Wet & Dry	Sand Protected	Abrasion	Wet & Dry	Sand Protected	Abrasion	Wet & Dry	Sand Protected	Abrasion	Wet & Dry
139-N	63	19	18	76	8	16	93	2	5	80	9	11
135-N	64	15	21	82	8	10	88	12	0	79	12	9
131-N	41	10	49	60	24	16	93	7	0	68	12	20
121-N	0	6	94	10	10	80	31	19	50	16	13	71
122-N	11	11	78	32	16	52	50	36	14	34	23	43
112-N	12	10	78	4	22	74	39	10	51	23	13	64

DRILLED AREA 3

GROIN												
139-N	0	10	90	0	4	96	44	4	52	20	6	74
135-N	0	6	94	0	4	96	0	5	95	0	5	95
131-N	0	1	99	8	0	92	15	15	70	8	7	85
121-N	0	0	100	0	0	100	0	0	100	0	0	100
112-N	0	0	100	0	0	100	0	0	100	0	0	100

NATURALLY PERFORATED AREA

GROIN			
139-N	62	25	13(1)
125-N	52	16	32(1)
131-N	17	28	55(1)
121-N	38	10	52(2)

(1) Exposure for period from installation of groin to appearance of holes.

(2) Exposure for period, Aug 1941 through Aug 1946.

LOCATION OF EXPERIMENTAL GROINS

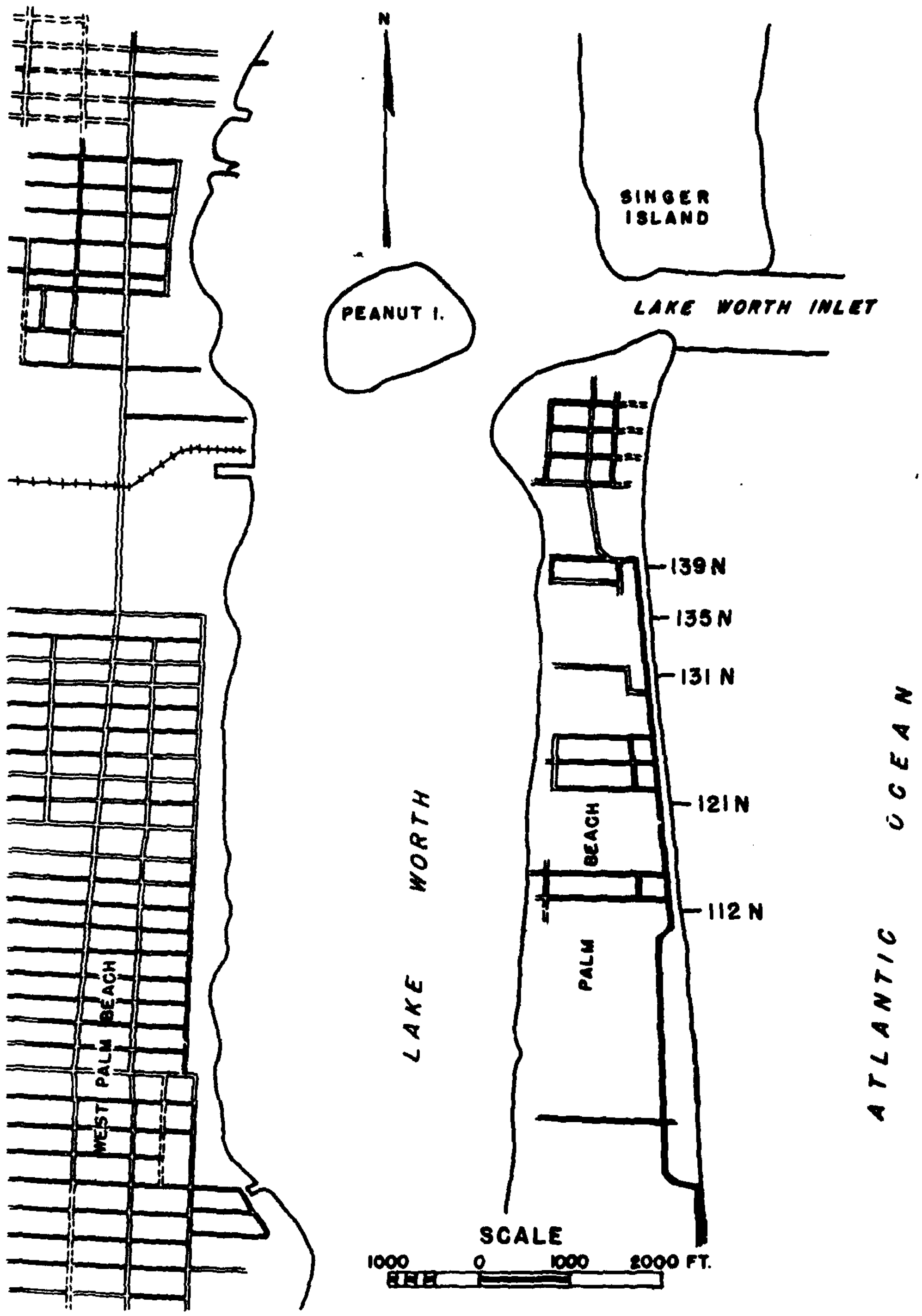
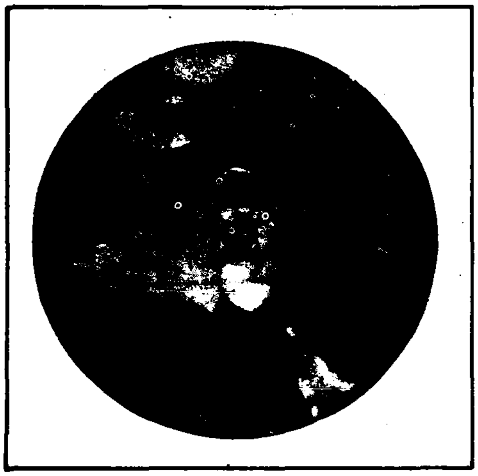


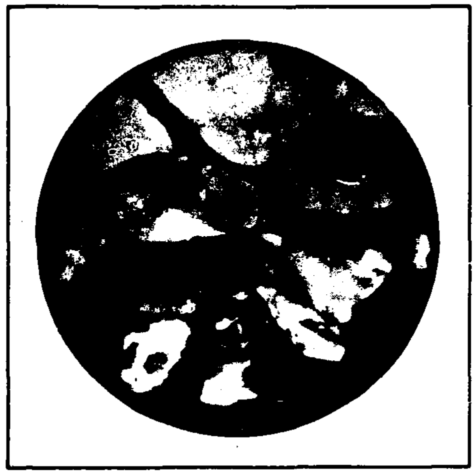
FIG. 1

SAND SAMPLES FROM
EXPERIMENTAL GROIN AREA,
PALM BEACH, FLORIDA

BETWEEN GROINS 112-N AND 121-N



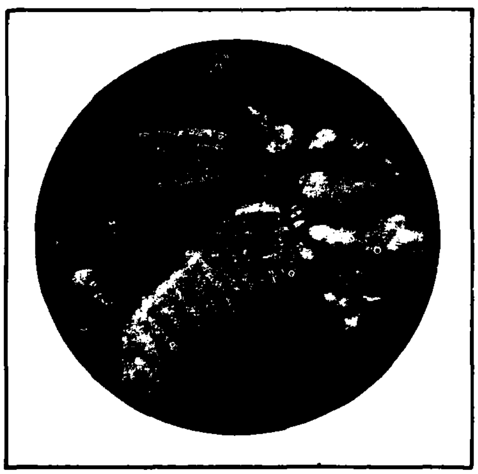
MAGNIFIED 20 DIAMETERS
SAND BEFORE LEACHING



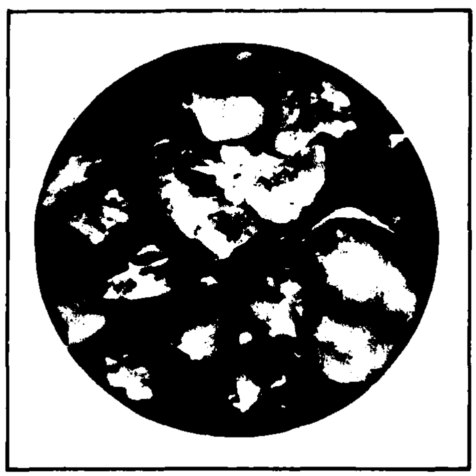
MAGNIFIED 20 DIAMETERS
SAND AFTER LEACHING

SHELL CONTENT		77 %
SPECIFIC GRAVITY (BEFORE LEACHING)		2.70
MEDIAN DIAMETER	"	.650

BETWEEN GROINS 121-N AND 131-N



MAGNIFIED 20 DIAMETERS
SAND BEFORE LEACHING



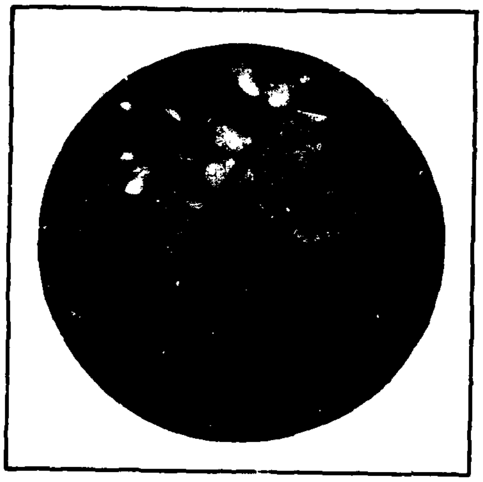
MAGNIFIED 20 DIAMETERS
SAND AFTER LEACHING

SHELL CONTENT		64 %
SPECIFIC GRAVITY (BEFORE LEACHING)		2.66
MEDIAN DIAMETER	"	.505

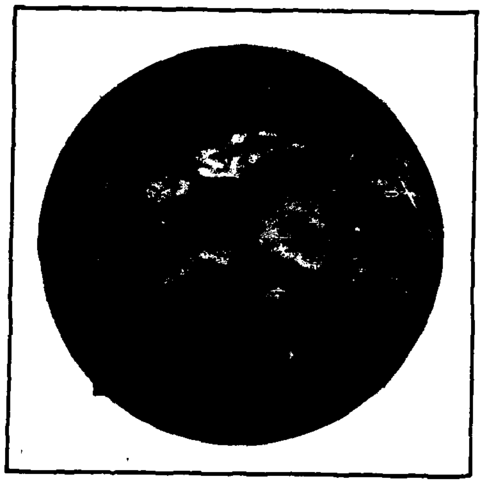
FIG. 2

SAND SAMPLES FROM
EXPERIMENTAL GROIN AREA,
PALM BEACH, FLORIDA

BETWEEN GROINS 131-N AND 135-N



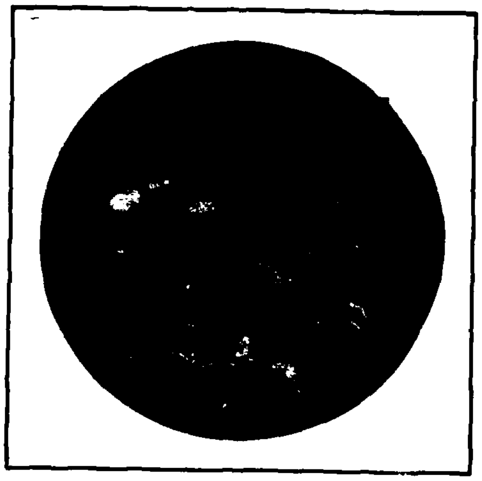
MAGNIFIED 20 DIAMETERS
SAND BEFORE LEACHING



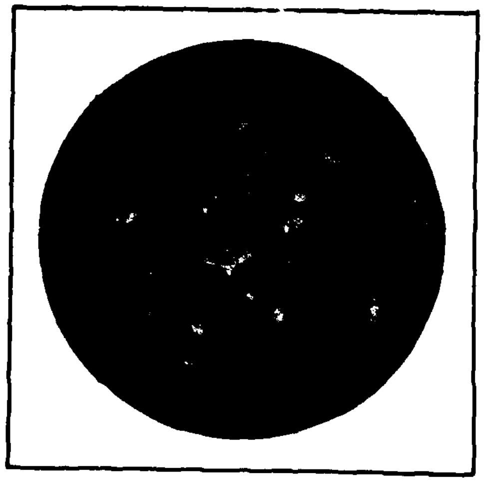
MAGNIFIED 20 DIAMETERS
SAND AFTER LEACHING

SHELL CONTENT	56 %
SPECIFIC GRAVITY (BEFORE LEACHING)	2.71
MEDIAN DIAMETER "	.449

BETWEEN GROINS 135-N AND 139-N



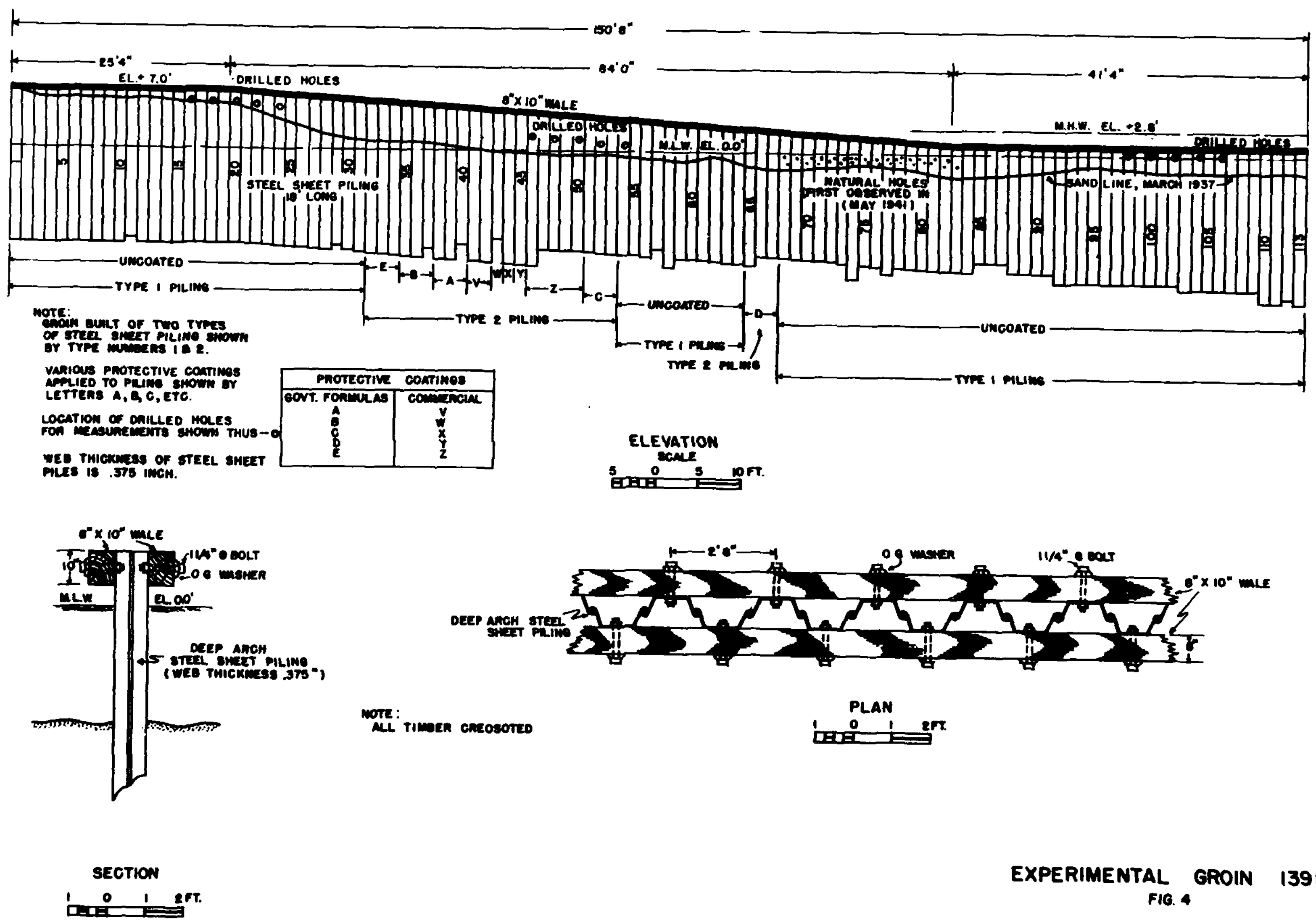
MAGNIFIED 20 DIAMETERS
SAND BEFORE LEACHING



MAGNIFIED 20 DIAMETERS
SAND AFTER LEACHING

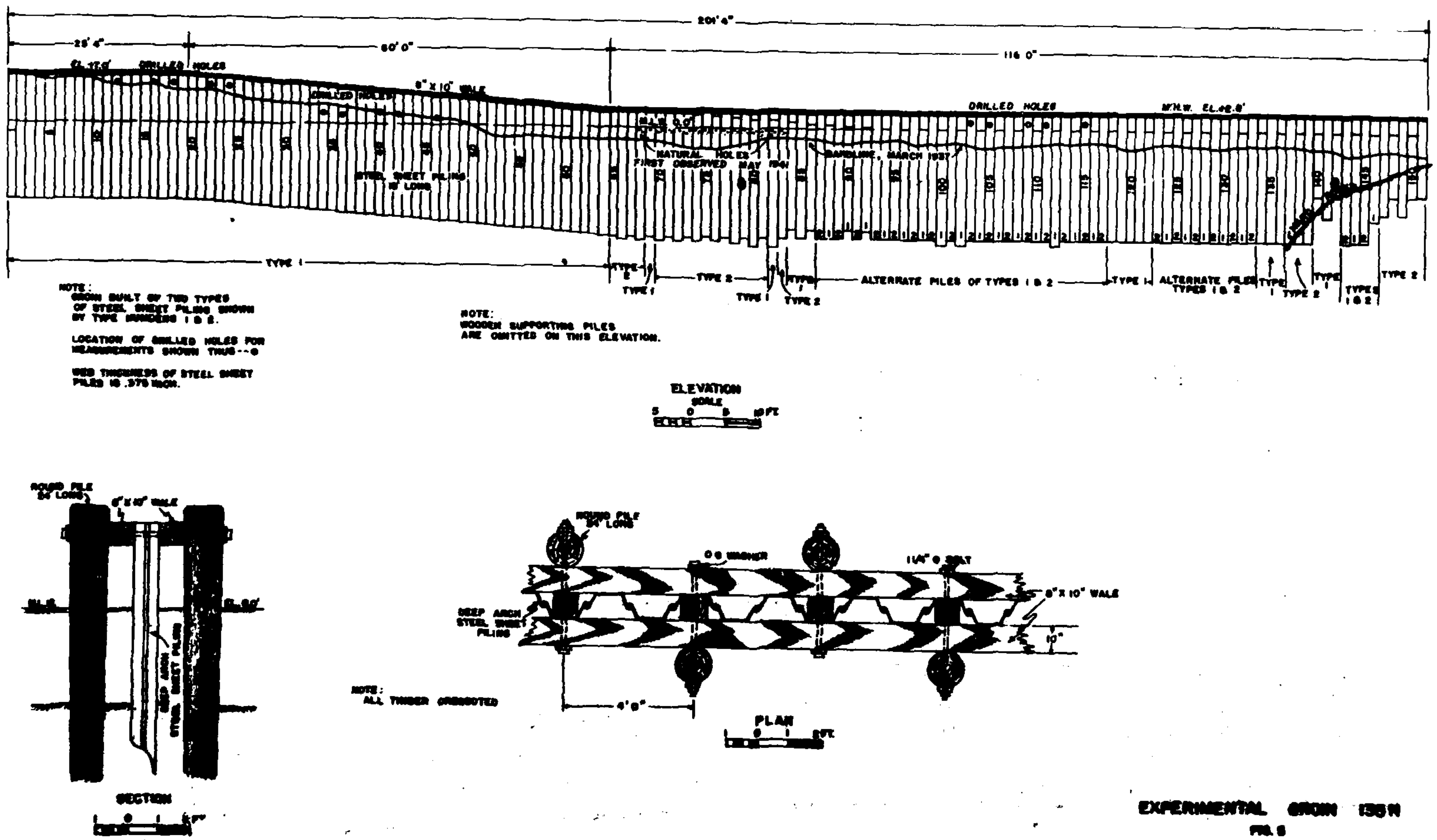
SHELL CONTENT	59 %
SPECIFIC GRAVITY (BEFORE LEACHING)	2.72
MEDIAN DIAMETER	.400

FIG. 3



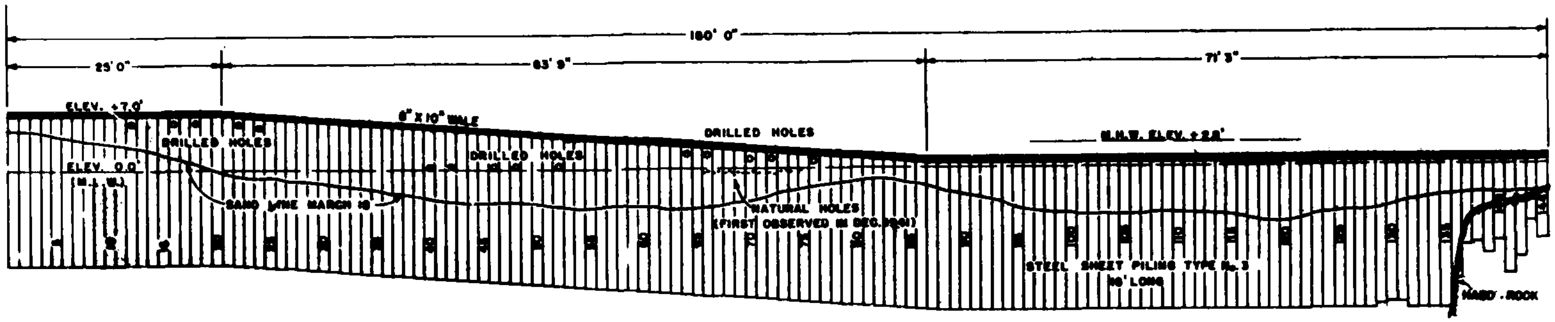
EXPERIMENTAL GROIN 139N

FIG. 4



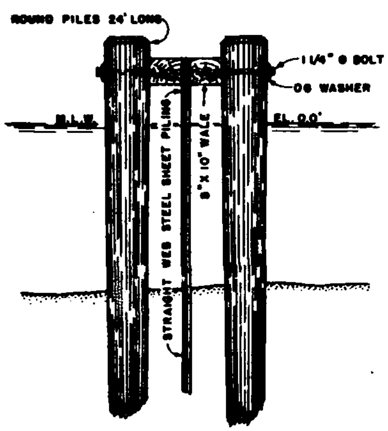
EXPERIMENTAL GROIN 1361

FIG. 6

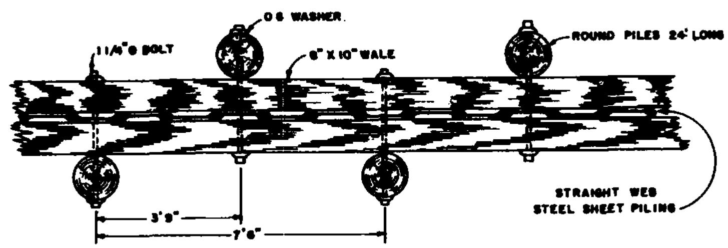


NOTE:
LOCATION OF DRILLED HOLES
FOR MEASUREMENTS SHOWN THUS ---O

ELEVATION
SCALE
5 0 5 10 FT



SECTION
SCALE
1 0 1 2 FT.

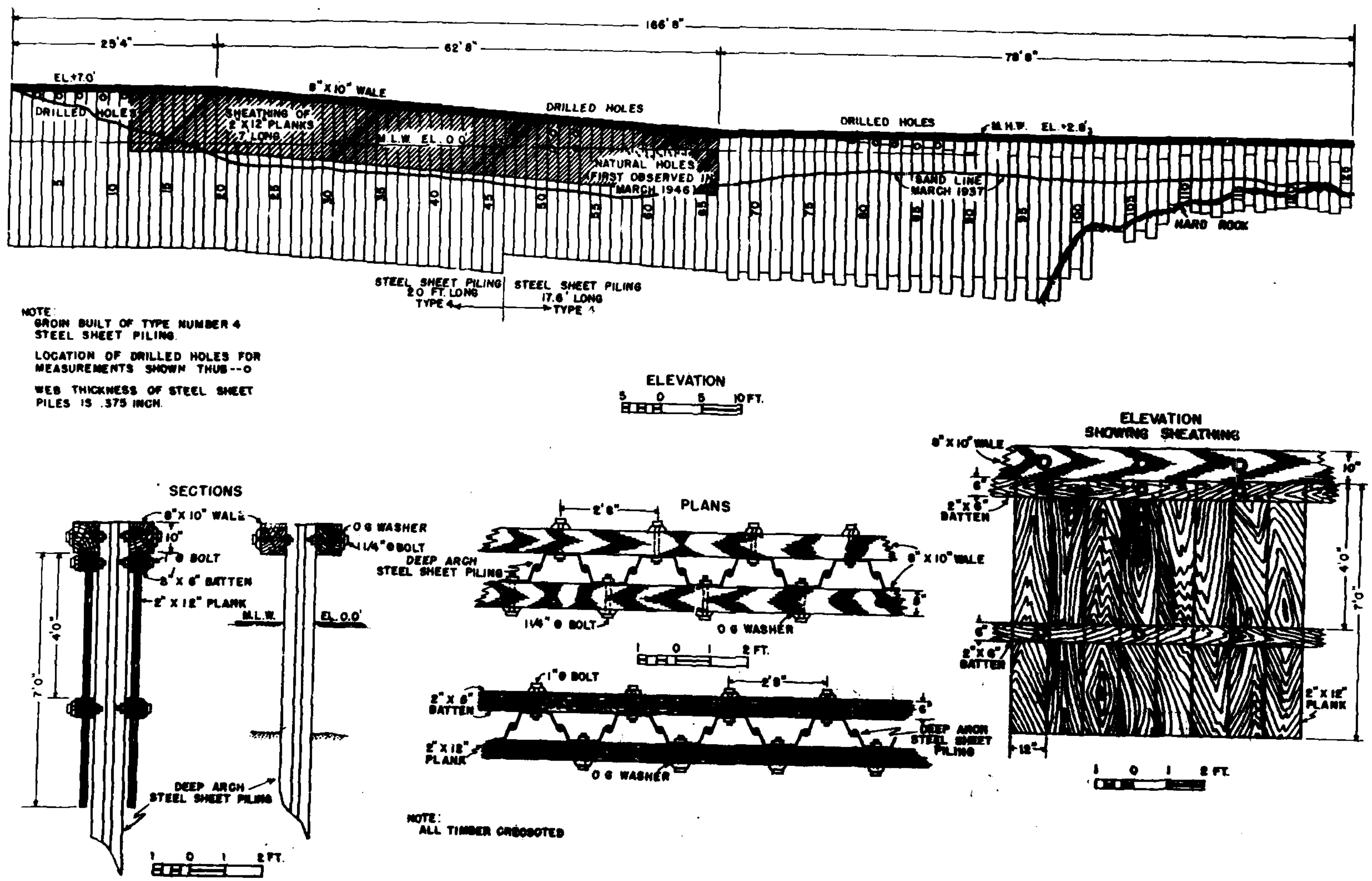


PLAN
SCALE
1 0 1 2 FT.

NOTE:
ALL TIMBER CREOSOTED

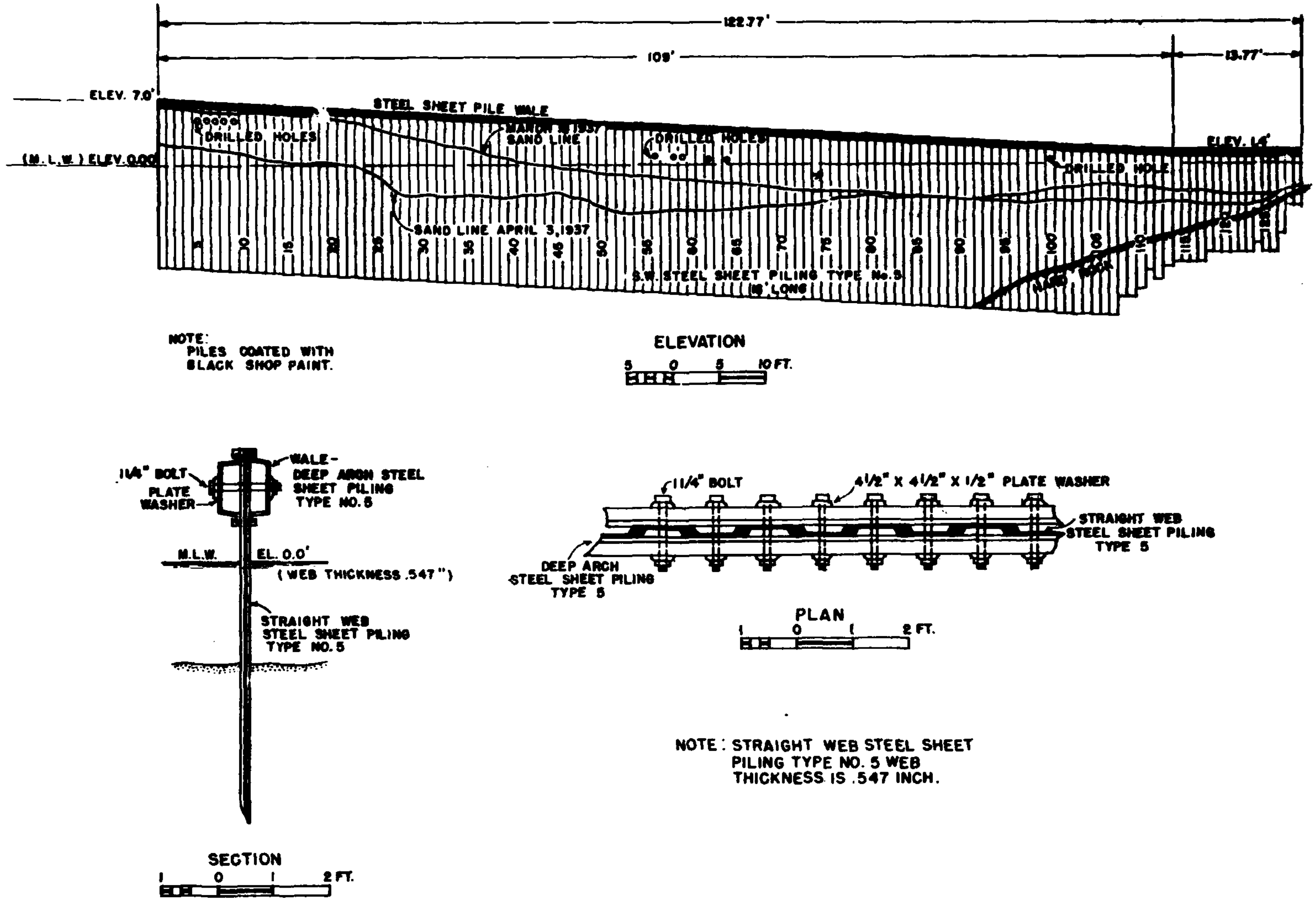
WEB THICKNESS OF STEEL SHEET
PILES IS .375 INCH.

EXPERIMENTAL GROIN 131 N
FIG. 6



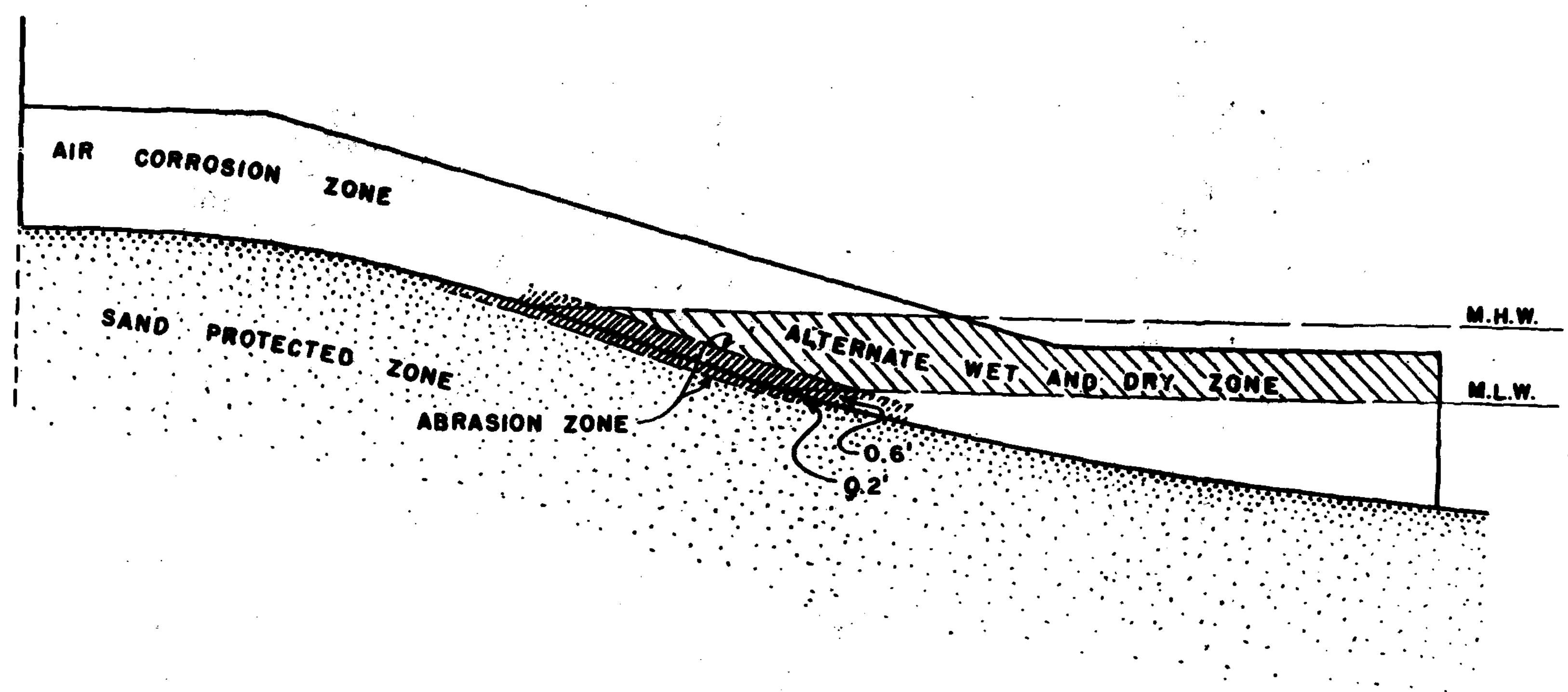
EXPERIMENTAL GROIN 121 N

FIG. 7



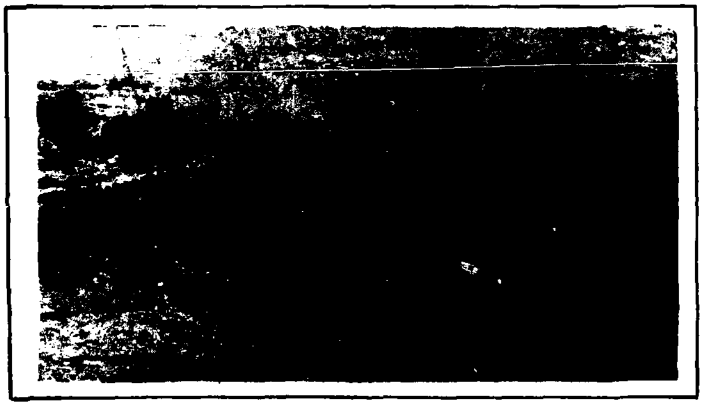
EXPERIMENTAL GROIN 112 N

FIG. 8

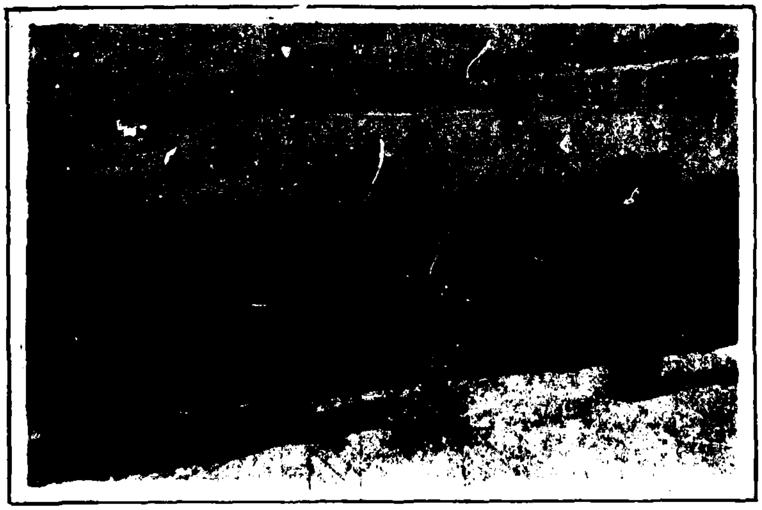


CONDITIONS OF GROIN EXPOSURE
FIG. 9

GROIN 139-N JUNE 1942



GROIN 135-N JUNE 1942

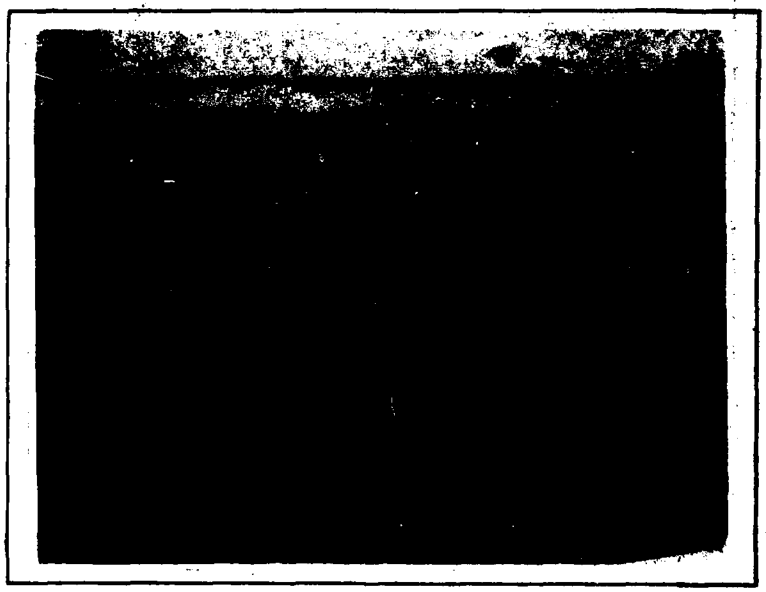


GROIN 131-N JUNE 1946

VIEWS OF EXPERIMENTAL GROINS

FIGURE 10

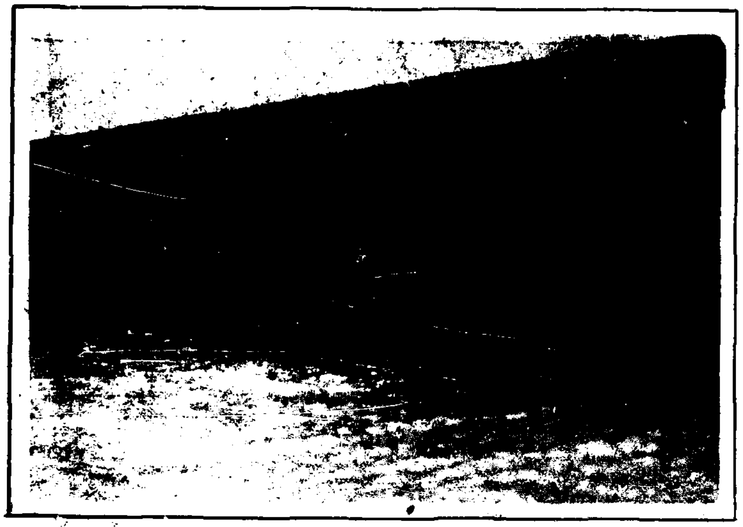
GROIN 121-N JUNE 1942



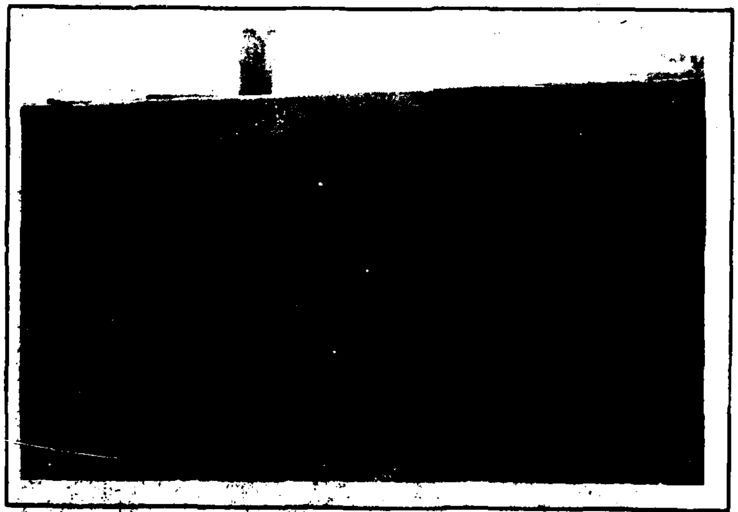
GROIN 112-N JULY 1946

VIEWS OF EXPERIMENTAL GROINS

FIGURE 11



AUGUST 1940



JUNE 1946

VIEWS OF TIMBER SHEATHING EXPERIMENTAL GROIN 121-N

FIGURE 12

APPENDIX I

Paint Formulas

Government Specified Formulas

A. Liquid coal tar (refined, non-acid high melting point) .... 8 gallons

Portland cement .... 11 pounds

Kerosene .... 1 gallon

Do not apply heat to mixture and use within 5 hours after mixing. Quantity covers about 1200 square feet.

B. Liquid coal tar (refined, non-acid)

Apply hot and saturate with sand while still soft.

C. Liquid coal tar (refined, non-acid, high melting point)

Apply with brush while hot.

D. Asphalt (refined Trinidad) .... 1 part

Coal tar (straight run) .... 3 parts

Heat to 300° F and apply with brush.

E. Pure red lead .... 100 pounds

Raw linseed oil .... 4 gallons

Japan (free from benzine) .... 1/2 pint

APPENDIX II

Analysis of the Steel used in the Groins

One sample of steel was taken from one pile of each type of steel sheet piling used in the groins. The location of the piles is given in Figures 4 to 8. The pile number is counted from the bulkhead. The samples were analyzed by the National Bureau of Standards. All the determinations except carbon and manganese were made by the spectrochemical analysis method. The values found are as follows:

Type	Identification	C	Mn	Si	Cu	Ni	Cr	V	Mo
1	Groin 139-N Pile 6	0.39	0.76	< 0.06	0.05	< 0.1	.03	< .03	< .1
2	Groin 135-N Pile 73	.23	.96	.09	.04	< .1	.03	< .03	< .1
3	Groin 131-N Pile 56	.21	.65	< .06	.03	< .1	< .02	< .03	< .1
4	Groin 121-N Pile 30	.33	.84	.14	.03	< .1	< .02	< .03	< .1
5	Groin 112-N Pile 54	.29	.82	.07	.35	< .1	.05	< .03	< .1

These data must not be used in full or in part for advertising purposes or sales promotion.