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SUMMARY OF EXPERIMENTAL PILING INSPECTIONS AT PEARL HARBOR, HAWAII

ABSTRACT Two hundred seventy-three treated Douglas-fir and southern pine piling were installed at Pearl Harbor, Hawaii from 1963 to 1966 and periodically inspected to determine cross-sectional area loss caused by teredine, limnorian, and pholad marine borers. All piling treated with creosote and copper-nickel sheathing, chlordane, creosote and dieldrin, basic zinc sulfate, and most piling treated with an arsenical salt and creosote (dual treatment) have sustained little loss. Piling treated with phenylmercuric oleate in creosote or with copper oxinate have performed relatively well. Arsenical salt treatments (at low retentions), treatments of copper naphthenate with creosote, and most creosote treatments are rated fair to good. Two creosote treatment groups have sustained little loss. In general, little or no apparent enhancement of performance was imparted by the inclusion of Victoria green base, tributyltin oxide, or copper sulfate to treatment chemicals tested.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

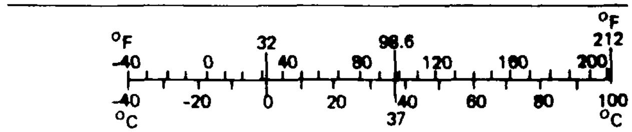
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Two hundred seventy-three treated Douglas-fir and southern pine piling were installed at Pearl Harbor, Hawaii from 1963 to 1966 and periodically inspected to determine cross-sectional area loss caused by teredine, limnorian, and pholad marine borers. All piling treated with creosote and copper-nickel sheathing, chlordane, creosote and dieldrin, basic zinc sulfate, and most piling treated with an arsenical salt and creosote (dual treatment) have sustained little loss. Piling treated with phenylmercuric oleate in creosote or with copper oxinate have performed relatively well. Arsenical salt treatments (at low retentions), treatments of copper naphthenate with creosote, and most creosote treatments are rated fair to good. Two creosote treatment groups have sustained little loss. In general, little or no apparent enhancement of performance was imparted by the inclusion of Victoria green base, tributyltin oxide, or copper sulfate to treatment chemicals tested.

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CONTENTS

INTRODUCTION

The efficacy of a wood preservative in preventing marine borer damage can be determined by the marine exposure of either treated small wood panels or full-size timber piling. Small panel testing provides an inexpensive, accelerated means of determining the relative worth of experimental treatments but a more accurate determination requires the installation of treated, full-size piling.

The Naval Civil Engineering Laboratory (NCEL) installed 273 experimental piling at Pearl Harbor, Hawaii, during the years 1963 through 1966 (Figure 1). The piling driven in 1963 were produced by the Kopper's Company for the Cooperative Marine Piling Committee (COOP). The COOP included representatives from NCEL, the wood-treating industry, the Forest Products Laboratory, and the W.F. Clapp laboratory (now Batelle Laboratories). The piling installed from 1964 to 1966 were produced and driven solely under the guidance of NCEL. The treatment chemicals selected were first included in laboratory screening tests, in which the antiborer activity of 786 chemicals was determined, followed by small panel exposure testing of the most promising agents (Ref 1). Although many of the piling have been accidentally or deliberately removed or completely destroyed by marine borers, the value of the remaining test piling increases yearly as the relative efficacies of the various treatments become evident.

This report is an update of the 1987 inspection summary report (Ref 2).

PILING TREATMENTS AND INSTALLATIONS

A summary of piling treatments with the year driven is provided in Table 1. All piling were pressure-treated and were driven near Waipio Peninsula, Pearl Harbor, Hawaii. Details of original treatments and installations can be found in References 3 through 7; brief descriptions of treatments, installations, and removals are provided below.

All Douglas-fir and southern yellow pine piling installed in 1963 were pressure-treated with creosote and most were also treated with another preservative (dual treatment). Of the 66 piling driven in 1963, 42 were inadvertently removed in August 1972. Most broke during removal, while some were lost or could not be identified. Four of the piling were redriven in May 1973; thus, 28 piling remained for subsequent inspections. One was subsequently reported broken by impact and lost in 1978.

In 1964, 69 creosoted Douglas-fir piling were driven. Most piling were treated with one or two additional preservatives. Four piling in this group were removed in 1982 and examined to assess the accuracy of visual inspection techniques.

All of the 78 Douglas-fir piling installed in 1965 were accidentally removed in 1972; 47 were redriven in 1973. One of these piling was removed in 1982 for examination at NCEL. The treatments included experimental preservatives in xylene or in creosote.

The last series, consisting of 60 Douglas-fir piling, were installed in 1966. A variety of single and dual treatments were employed. None of these piling were lost in 1972 but six were purposely removed in 1982.

PILING INSPECTIONS

From 1975 to 1989, eight underwater inspections were completed by professional divers. The piling are cleaned of surface fouling and then evaluated visually and by touch from the mud line to high water. Diver inspection reports include for each pile: (1) an estimate of the percent loss of cross-sectional area in the region of greatest damage, (2) any boring organisms present, and (3) any splits, checks, or other damage present. In a few cases, untreated heartwood was exposed by checks that occurred after treatment, e.g., during pile driving; borer damage to this heartwood was largely discounted by divers when estimating cross-sectional loss.

Visual examinations can readily detect damage caused by Limnoria tripunctata, a crustacean, and Martesia striata, a wood-boring clam (pholad), both prevalent in Pearl Harbor. Damage by shipworms (teredines), also abundant in Hawaiian waters, is mainly internal and difficult for divers to observe directly. Diver inspection reports, however, indicated that the majority of damage was caused by Limnoria and that any shipworm attack was most often preceded by extensive Limnoria damage. In order to confirm this observation and evaluate the accuracy of visual inspections, the 1982 inspection also included direct observations of nine piling removed from the water one week after visual inspections. These piling were cut in the area of greatest damage and photographed. Sound wood was outlined on the photographs and a planimeter was used to determine cross-sectional area. From these data, cross-sectional area loss for each pile was calculated and compared with diver estimates (Table 2). Observations of cut piling confirmed that the majority of damage was caused by Limnoria. Where cut piling had an actual cross-sectional loss of 13% or less, the diver estimates were close to actual damages. Where cut piling had an actual cross-sectional loss from 31 to 65%, the diver estimates were consistently lower (about 1/2 of actual damage).

INSPECTION RESULTS

The performances of the various treatments are included in Tables 3 through 7 in terms of the average number of years of exposure until piling cross-sectional area loss as determined by diver inspections exceeded 5%, 15%, and 50%. In those cases where a number of years passed between inspections and rapid change occurred, the years of exposure until a loss category was reached is determined by extrapolation. For those piling inadvertently removed in 1972 and then redriven in 1973, the time spent out of the water is discounted in determining years of exposure. Most treatment retention values listed in Tables 3 through 7 were determined by analysis of core borings before installation; some were determined by treatment gage measurement at the time of treatment.

Where all the piling of a particular treatment have not yet exceeded an area loss category, the average number of exposure years for that category cannot be calculated. In those cases, the number of piling remaining which did not exceed that cross-sectional loss category by 1989 are given in parentheses in Tables 3 through 7. For example, in Table 3 it can be seen that five Douglas-fir piling treated with marine grade creosote were driven in 1963. All five sustained a loss of more than 15% by 1989. It took an average of 19.5 years for the loss to exceed 5% and an average of 23.4 years for the loss to exceed 15%. In addition, two piling have lost a cross-sectional area greater than 15% but not greater than 50% by the 1989 inspection. The remaining three piling have lost a cross-sectional area greater than 50%.

Early inspections reported that the majority of damage was caused by a boring clam, Martesia striata, with limited attack by the crustacean, Limnoria tripunctata. No shipworms were found. Later inspections reported increased Limnorian attack and it is now the major cause of damage to most piling. Martesia are, however, the main cause of damage to salt-treated piling (i.e., treated with BZS, ACA, or CCA) that have sustained damage of 20% or less. Some shipworm damage is reported in recent inspections in association with extensive limnorian attack. These observations do not preclude the possibility that some internal shipworm attack has occurred unnoticed.

DISCUSSION

It has been only after the most recent inspections that some differences in treatment efficacies could be measured. The treated piling have generally lasted a very long time. This longevity is likely a result of the inherent worth of the treatments and the care taken in treatments and installations.

It is evident that loss of piling cross-sectional area in this test proceeds in two stages. The initial stage is represented by the number of years it takes to sustain a loss of greater than 5%. This stage is generally slow and reflects the level of protection the treatment offers. After a pile has suffered a loss of from 5% to 10% the damage proceeds rapidly; the loss rate during this latter stage apparently differs little between treatments. Many of the Hawaii experimental piling have only recently begun this rapid stage of deterioration.

Creosote Treatments

The performances of creosote-treated piling are inconsistent but the majority of treatments have performed well (Table 3). No consistent relationship between performance and preservative retention is evident between treatment groups. Only one piling group of three treated with marine grade creosote was heavily damaged as of the 1989 inspection.

Likewise, only one group of three treated with 70-30 creosote-coal tar was heavily damaged. This performance range makes direct comparisons of other treated piling with creosoted piling difficult. The wide variation in performance of seemingly like-treated piling has often plagued those charged with the task of assessing the relative efficacies of preservative treatments.

Limnoria are the principal agents of damage to creosoted wood. Shipworms apparently become established only after the heartwood is exposed by limnorian attack. Martesia damage to these piling is generally limited.

Other Single Treatments

Basic zinc sulfate has been the most successful single treatment in this test followed by copper oxinate (Table 4). The relatively good performances of these treatments along with their low environmental hazard may warrant further development of these preservatives. Single treatments of ammoniacal copper arsenate (ACA) and chromated copper arsenate (CCA) at low retentions have not performed as well. The recommended retention for these modern, multi-salt treatments, however, is 2.5 pcf for marine use; this is considerably greater than the retentions of the Hawaii test piling.

Borer damage to salt-treated timber is generally initiated by Martesia. The holes caused by these borers apparently provide an entry for Limnoria and shipworms into inner layers of the wood that have less preservative retention.

Dual Treatments With Creosote

Creosote treatments in combination with ACA, CCA at 2.7 pcf, or chlordane (a chlorinated organic pesticide) at 0.3 pcf have performed very well in these tests (Table 5). An exception is the CCA-creosote piling with a creosote retention of only 8.4 pcf and CCA retention of 1.7 pcf; these piling are all now severely damaged. Current AWPA recommendations call for 20 pcf creosote and 1.0 pcf arsenical salt for dual-treated piling. Chlordane is an apparently effective additive to creosote, but its use is unlikely because of environmental concerns.

Piling pressure-treated with a combination of creosote and phenylmercuric oleate (PMO) have generally endured. Analyses of core borings after treatment showed that considerably less than the nominal percentage of PMO got into the wood. Improved performance is likely if a greater PMO retention can be affected. Any mercurial compound, however, would be an unlikely candidate for marine wood preservation because of a high potential environmental hazard.

The one remaining creosoted piling that is completely covered with copper-nickel sheathing is still intact with the sheathing showing some corrosion but still apparently effective. Several like-treated piling were removed accidentally in 1972 and not redriven. The sheathings on these piling were reported to be severely corroded about midway between the mud line and high tide mark.

Dual-treated piling containing creosote and copper naphthenate have performed reasonably well. The relatively low preservative concentrations in these piling suggest that greater protection is possible with higher concentrations.

The addition of tributyltin oxide (TBTO) to creosote treatments provided no apparent additional protection.

Dual Treatments Without Creosote

This test indicates that the performance of copper oxinate as a wood preservative in the marine environment is not enhanced by the inclusion of tributyltin oxide (TBTO), a controversial but effective antifoulant, or Victoria green base, a common dye (Table 6). Piling treated with TBTO in combination with CCA, ACA, or basic zinc sulfate, on the other hand, have lasted slightly longer than respective piling treated with nearly equal amounts of these salts without TBTO. TBTO in combination with copper sulfate has been relatively ineffective. The inclusion of TBTO in piling treatments is now unlikely because of environmental constraints.

Multiple Preservatives With Creosote

Piling treated with copper naphthenate and creosote with added TBTO have performed similarly to piling with similar retentions of the dual treatment without TBTO (Table 7). Likewise, piling treated with creosote, copper oxinate, and Victoria green base have performed no better than like-treated piling but without creosote. The very good performance of piling treated with a combination of creosote, TBTO, and the chlorinated organic, dieldrin, is tempered by the unlikely environmental acceptability of this chlorinated pesticide.

FINDINGS AND CONCLUSIONS

1. Visual inspections of these experimental piling by divers provide an accurate assessment of borer damage when there is very little or severe cross-sectional loss. Pile damage estimates are generally lower than actual damages when cross-sectional losses are from 15 to 60%.

2. Damage to creosoted piling is primarily by limnorians. Damage to salt-treated piling is initiated by pholads, but in later stages damage is mainly by Limnoria. Some shipworm attack is evident in most severely damaged piling.

3. Damage to piling proceeds in two stages. The length of the first stage (until cross sectional loss is 5% or greater) is a fair measure of treatment efficacy. Soon after damage exceeds 5%, Limnoria and shipworms are established and damage rapidly accelerates.

4. The following treatments are considered excellent (more than 20 years average exposure until cross-sectional loss greater than 5%) and are listed in approximate order of success:

Creosote (17.4 pcf), TBTO (0.18 pcf), and dieldrin (0.18 pcf)
Creosote (24.3 pcf) and Cu-Ni sheathing
Creosote (26.3 - 28.6 pcf) and chlordane (0.3 - 1.4 pcf)

Creosote (16.2 - 19.6 pcf) and ACA (0.51 pcf)
Basic zinc sulfate (2.66 pcf) and TBTO (0.20 pcf)
Creosote (23.2 pcf) and CCA (2.7 pcf)
Chlordane (1.3 - 1.5 pcf) and TBTO (0.27 - 0.62 pcf)

4. The following treatments are considered good (from 15 to 20 years average exposure until cross-sectional loss greater than 5%) and are listed in approximate order of success:

Basic zinc sulfate (2.77 pcf)
Creosote (13.0 - 27.5 pcf) and phenylmercuric oleate (1 - 5%)
ACA (0.51 pcf) and TBTO (0.11 pcf)
Copper oxinate (0.49 - 0.87 pcf)
Creosote (15.3 - 32.9 pcf)
Creosote (8.3 - 10.9 pcf) and copper naphthenate (0.09 - 0.27 pcf)
CCA (0.5 pcf) and TBTO (0.13 pcf)
Copper oxinate (0.69 pcf) and Victoria green base (0.26 pcf)
ACA (0.51 pcf)
Creosote (8.4 pcf) and CCA (1.7 pcf)

5. The following treatments are considered poor to fair (less than 15 years average exposure until cross-sectional loss greater than 5%) and are listed in approximate order of success:

Creosote (8.6 - 10.9 pcf), copper naphthenate (0.09 - 0.27 pcf) and TBTO (0.08 - 0.15 pcf)
Creosote (9.2 - 24.7 pcf), copper oxinate (0.25 - 0.27 pcf), and Victoria green base (0.08 - 0.09 pcf)
Copper oxinate (0.25 pcf) and TBTO (0.25 pcf)
Copper sulfate (0.03 - 0.06 pcf) and TBTO (0.19 - 0.20 pcf)
Creosote (13.9 pcf) and TBTO (0.14 pcf)
CCA (0.5 pcf)

RECOMMENDATIONS

1. Additional inspections of these experimental piling in Hawaii should be completed. It is anticipated that many treatment systems under test will continue to provide excellent marine borer protection for many more years and should be evaluated on a timely basis.

2. The continued success of basic zinc sulfate warrants further investigation as an environmentally acceptable alternative to creosote, CCA, and ACA for marine timber.

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3. Naval Civil Engineering Laboratory. Technical Note N-503: Cooperative marine piling investigation, phase 2 - Pile driving at Pearl Harbor, Hawaii, by H. Hochman. Port Hueneme, CA, Jul 1963.

4. _______. Technical Note N-672: Experimental wood piling treatments FY-64, by T. Roe, Jr. and H. Hochman. Port Hueneme, CA, Dec 1964.

5. _______. Technical Note N-677: Driving of piling treated with creosote containing additives, by H. Hochman. Port Hueneme, CA, Dec 1964.

6. _______. Technical Note N-736: Experimental wood piling treatments FY-65, by T. Roe, Jr. and H. Hochman. Port Hueneme, CA, Aug 1965.

7. _______. Technical Note N-898: Experimental wood preservative systems: Treatment FY 66; Driving FY 67, by H. Hochman and T. Roe, Jr. Port Hueneme, CA, Jan 1967.

Table 1. Index to Treatment Performance Tables

Treatment	Year Installed	Table No.
Creosote:		
Marine Grade	1963,1964	3
70-30 Creosote-Coal Tar	1963,1966	3
Other Single Treatments:		
Copper oxinate	1965	4
Basic zinc sulfate	1966	4
Ammoniacal copper arsenate	1966	4
Chromated copper arsenate	1966	4
Dual Treatments With Creosote and:		
Ammoniacal copper arsenate	1963,1966	5
Chromated copper arsenate	1963	5
Phenylmercuric oleate	1963	5
Chlordane	1964	5
Copper naphthenate	1964	5
Tributyltin oxide	1964	5
Copper-nickel sheathing	1966	5
Other Dual Treatments:		
Copper oxinate & tributyltin oxide	1965	6
Copper oxinate & Victoria green base	1965	6
Chlordane & tributyltin oxide	1965	6
Chromated copper arsenate & tributyltin oxide	1966	6
Basic zinc sulfate & tributyltin oxide	1966	6
Ammoniacal copper arsenate & tributyltin oxide	1966	6
Copper sulfate & tributyltin oxide	1966	6
Multiple Treatments With Creosote and:		
Copper naphthenate & tributyltin oxide	1964	7
Tributyltin oxide & dieldrin	1964	7
Copper oxinate & Victoria green base	1965	7

Table 2. Diver Estimates of Damage to Selected Piling Compared with Actual Damage Determined After Removal in 1982

Piling Treatment	Cross-Sectional Area Loss %	
	Actual	Estimated
Creosote & TBTO & dieldrin	0	2
Basic zinc sulfate	2	2
Ammoniacal copper arsenate	11	18
30% Copper naphthenate	13	9
Creosote & copper oxinate and Victoria green base	31	8
Ammoniacal copper arsenate	42	30
Ammoniacal copper arsenate	50	11
15% Copper naphthenate	65	28
Copper sulfate and TBTO	65	45

Table 3. Performances of Creosote-Treated Piling

Treatment	Year Driven	Average Retention (pcf)	Number of Piles and Species	Average Years Exposure Until X-Sectional Loss Greater Than		
				5%	15%	50%
Marine grade creosote	1963	17.2	5 DF	19.5	23.4	(2)[b]
	1964	18.6	4 DF	10.5	11.0	15.3
	1964	32.9	6 DF	19.2	(3)[a]	(2)[b]
70-30 creosote-coal tar	1963	11.1	3 DF	21.0	(1)[a]	(2)[b]
	1963	13.5	2 SP	14.0	17.0	21.0
	1966	31.7	6 DF	16.8	(3)[a]	(2)[b]

a = number piles in 1989 with X-sectional loss greater than 5% but not greater than 15%

b = number piles in 1989 with X-sectional loss greater than 15% but not greater than 50%

Table 4. Performance of Piling With Single Treatments Other than Creosote

Treatment	Year Driven	Average Retention (pcf)	Number of Piles and Species	Average Years Exposure Until X-Sectional Loss Greater Than		
				5%	15%	50%
Copper oxinate	1965	0.49	6 DF	16.7	19.0	(5)[d]
	1965	0.87	6 DF	18.2	(1)[a]	(3)[d]
Basic zinc sulfate	1966	2.77	6 DF[c]	19.2	(2)[a]	(3)[b]
Ammoniacal copper arsenate	1966	0.51	6 DF[d]	15.5	17.0	19.7
Chromated copper arsenate (Type B)	1966	0.50	6 DF	9.7	11.5	12.3

a = number piles in 1989 with X-sectional loss greater than 5% but not greater than 15%
b = number piles in 1989 with X-sectional loss greater than 15% but not greater than 50%
c = 1 pile removed in 1982
d = 3 piles removed in 1982

Table 5. Performances of Piling Treated With Creosote and One Other Additive

Treatment	Year Driven	Average Retention (pcf)	Number of Piles and Species	Average Years Exposure Until X-Sectional Loss Greater Than		
				5%	15%	50%
Creosote & ammoniacal copper arsenate	1963	16.2	3 DF	24.3	(2)[b]	(1)[c]
	1966	19.6 0.51	6 DF	(1)[a]	(5)[b]	(0)[c]
Creosote & chromated copper arsenate	1963	8.4 1.7	3 DF	15.0	16.7	19.3
	1963	23.2 2.7	3[d]SP	23.0	(2)[b]	(0)[c]
Creosote & phenyl-mercuric oleate (1%)	1963	20.7	2 DF	23.0	(1)[b]	(1)[c]
		24.1	2 SP	18.0	20.0	(1)[c]
Creosote & phenyl-mercuric oleate (5%)	1963	13.0	1 DF	19.0	20.0	22.0
	1963	27.5	2 SP	18.5	21.0	(1)[c]
Creosote & copper-nickel sheathing	1963	24.3	1 DF	(1)[a]	(0)[b]	(0)[c]
Creosote & chlordane	1964	26.3 0.3	6[e]DF	21.0	(4)[b]	(0)[c]
	1964	28.5 0.7	6 DF	(2)[a]	(4)[b]	(0)[c]
	1964	28.6 1.4	6 DF	(4)[a]	(2)[b]	(0)[c]
Creosote & copper naphthenate	1964	10.9 0.09[g]	6 DF	16.5	17.7	(1)[c]
	1964	9.4 0.15[g]	6[e]DF	14.7	15.8	18.0
	1964	8.3 0.27[g]	6[f]DF	16.2	(1)[b]	(1)[c]
Creosote & tributyltin oxide	1964	13.9 0.14	5 DF	11.0	12.2	14.4

a = number piles in 1989 with X-sectional loss 5% or less
b = number piles in 1989 with X-sectional loss greater than 5% but not greater than 15%
c = number piles in 1989 with X-sectional loss greater than 15% but not greater than 50%
d = 1 pile destroyed by impact in 1978
e = 2 piles removed in 1982
f = 1 pile removed in 1982
g = as metallic copper

Table 6. Performances of Dual-Treated Piling Without Creosote

Treatment	Year Driven	Average Retention (pcf)	Number of Piles and Species	Average Years Exposure Until X-Sectional Loss Greater Than		
				5%	15%	50%
Copper oxinate & tributyltin oxide	1965	0.25 0.25	6 DF	13.3	15.5	18.2
Copper oxinate & Victoria green base	1965	0.69 0.26	5 DF	16.2	19.0	(2)[c]
Chlordane & tributyltin oxide	1965	1.3 0.27	6 DF	21.2	(4)[b]	(2)[c]
	1965	1.5 0.62	6 DF	(1)[a]	(5)[b]	(0)[c]
Ammoniacal copper arsenate & tributyltin oxide	1966	0.51 0.11	6 DF	(1)[a]	(2)[b]	(3)[c]
Chromated copper arsenate & tributyltin oxide	1966	0.50 0.13	6 DF	16.3	18.0	19.5
Basic zinc sulfate & tributyltin oxide	1966	2.66 0.09	6[a]DF	(2)[a]	(3)[b]	(0)[c]
Copper sulfate & tributyltin oxide	1966	0.03 0.20	6 DF	12.5	14.5	16.0
	1966	0.06 0.19	6[a]DF	12.3	14.8	17.4

a = number piles in 1989 with X-sectional loss 5% or less
b = number piles in 1989 with X-sectional loss greater than 5% but not greater than 15%
c = number piles in 1989 with X-sectional loss greater than 15% but not greater than 50%
d = 1 pile removed in 1982

Table 7. Performances of Multi-Treated Piling With Creosote

Treatment	Year Driven	Average Retention (pcf)	Number of Piles and Species	Average Years Exposure Until X-Sectional Loss Greater Than		
				5%	15%	50%
Creosote & copper naphthenate & tributyltin oxide	1964	8.6 0.07 0.08	6 DF	15.7	(1)[b]	(1)[b]
	1964	14.8 0.23 0.15	6 DF	13.0	15.0	16.8
Creosote & tributyltin oxide & dieldrin	1964	17.4 0.18 0.18	6 DF	(5)[a]	(0)[b]	(0)[c]
Creosote & copper oxinate & Victoria green base	1965	9.2 0.27 0.09	6 DF	12.8	15.0	17.2
	1965	24.7 0.25 0.08	6 DF	15.5	(1)[b]	(0)[c]

a = number piles in 1989 with X-sectional loss 5% or less
b = number piles in 1989 with X-sectional loss greater than 5% but not greater than 15%
c = number piles in 1989 with X-sectional loss greater than 15% but not greater than 50%
d = 1 pile removed in 1982

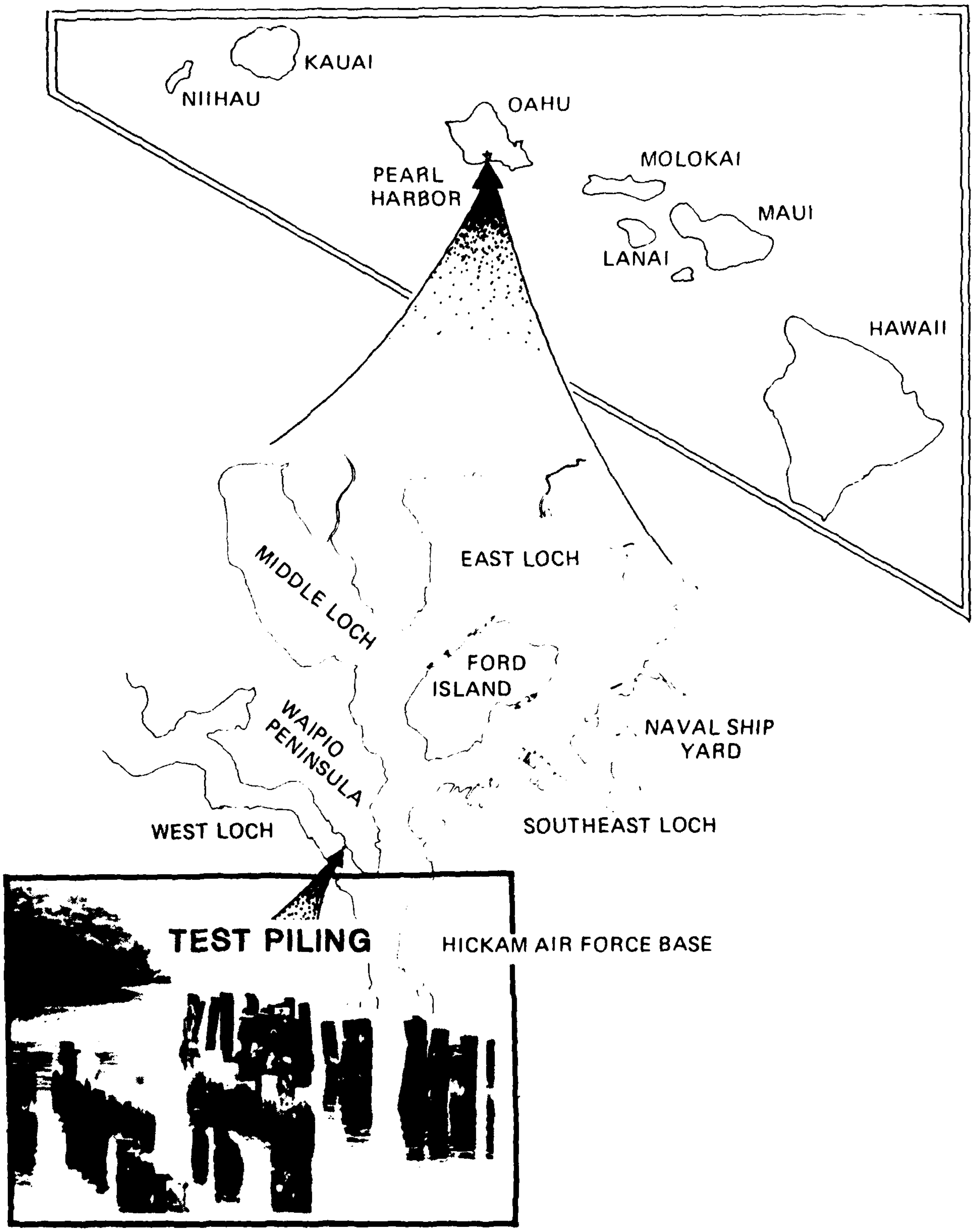

Figure 1. Location of experimental piling.

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