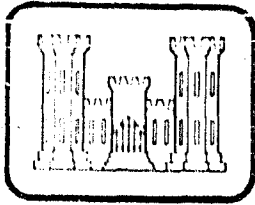LEVEL

MISCELLANEOUS PAPER HL-79-1

LEVEE WAVE WASH PROTECTION
BY TREES

Hydraulic Model Investigation

by

Dennis G. Markle

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
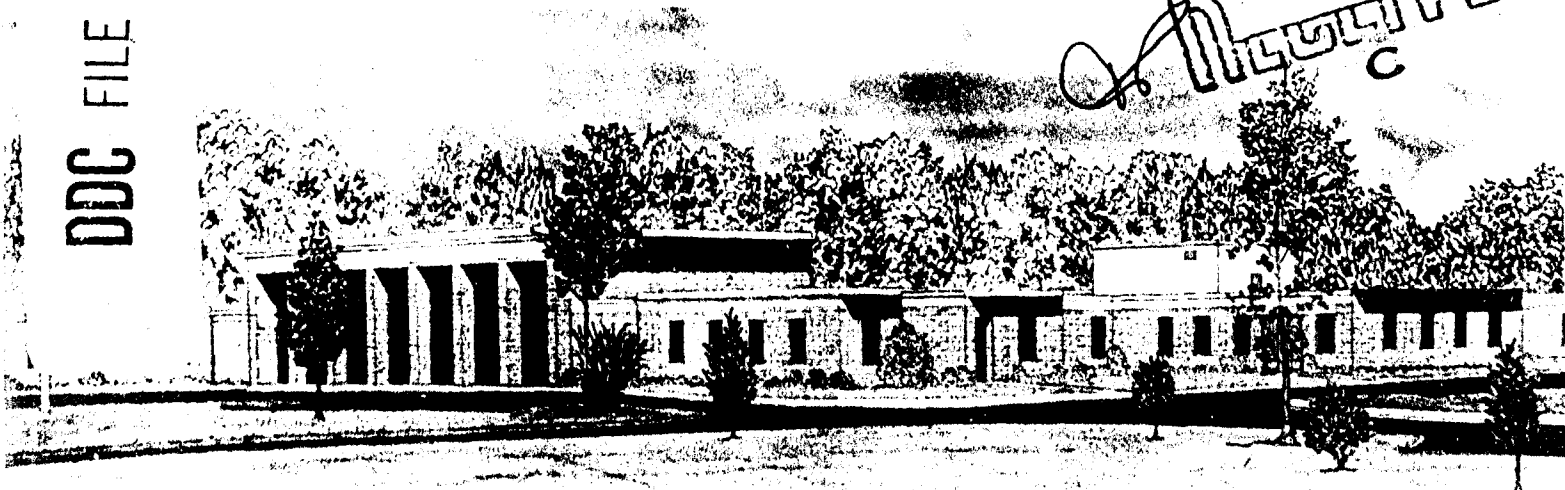P. O. Box 631, Vicksburg, Miss. 39180

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Final Report

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A hydraulic model investigation was conducted at a geometrically undistorted scale of 1:5, model to prototype. The purpose of the study was to test the use of tree stands as a possible method for protecting levee embankments from wave wash caused by wind- and boat-generated waves. Incident wave heights ranging from 1.0 to 3.0 ft and wave periods of 2.0, 2.5, and 3.0 sec were tested on a total of 12 different test plans. The 12 plans covered a

(Continued)

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20.   ABSTRACT (Continued).

range of depths of tree stands using exclusively 4-in.- and 12-in.-diameter
tree stems both with and without defoliated branch systems. The test results
showed that for tree stems without branches the wave attenuation did not
exceed a maximum of about 15 percent and on the average did not exceed about
9 percent. Tree stems with branch systems showed a maximum wave attenuation
of about 45 percent, but the average wave attenuation did not exceed 15 percent.

PREFACE

The model investigation reported herein was authorized by the U. S. Army Engineer District, Vicksburg (VED) Intra-Army Order No. 3239, dated 27 July 1976.

Model tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES) during the period September 1976 to February 1977 under the general direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory; Dr. R. W. Whalin, Chief of the Wave Dynamics Division; and Mr. D. D. Davidson, Chief of the Wave Research Branch (WRB). Tests were conducted by Mr. D. G. Markle, Hydraulic Research Engineer, WRB, with assistance from Mr. C. Lewis, engineering technician, WRB. This report was prepared by Mr. Markle.

Liaison was maintained during the course of this investigation by conferences, telephone calls, and progress reports.

Commander and Director of WES during the conduct of the study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

TABLE 1

PHOTOS 1-9

PLATES 1 and 2

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
degrees (angle)	0.01745329	radians

LEVEE WAVE WASH PROTECTION BY TREES

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. This investigation was not designated as a study for a
specific problem occurring in one area, but as a general investiga-
tion of the use of tree stands to help protect levee embankments
along inland waterways from wave wash caused by wind- and boat-
generated waves. The use of this native vegetation to attenuate
wave attack on the levees during high river stages would produce
benefits that are twofold. The obvious benefit would be the reduc-
tion in maintenance costs to repair the levees damaged by wave attack.
The other benefit would be the low initial and long-term maintenance
costs related to the use of naturally occurring vegetation rather
than conventional protection methods. In addition, the trees could
then be controlled and harvested, and new stands planted, thereby
producing a return on the investment. Cottonwood trees were selected
for test simulation because of their fast growth rate and suitability
to flood zone areas. Since there are an infinite number of tree
patterns and spacings that could be employed in the prototype, the
tests described herein were limited to one pattern and spacing, which
was considered an optimum planting arrangement.

Purpose of Model Study

2. The purpose of the hydraulic model study was to measure
the wave attenuation produced by cottonwood trees when the water
level passed through the tree stems and when the water level passed
through the branch system of the trees. These data could then be

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TREES   TREES

LEVEE   LEVEE

RIVER CHANNEL
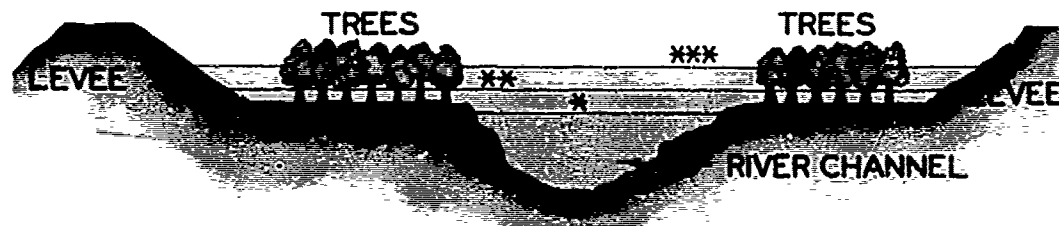
*   NORMAL RIVER WATER LEVEL
**   WATER LEVEL TESTED THROUGH STEMS
*** WATER LEVEL TESTED THROUGH BRANCHES

Figure 1. Levee wave wasn protection by trees

be used to approximate the amount of wave protection during various
river stages that could be expected from a stand of trees planted
between a river channel and levee embankment (Figure 1).

PART II: THE MODEL

Selection of Test Scales

3. Tests were conducted at a geometrically undistorted linear scale of 1:5, model to prototype. Scale selection took into consideration the materials necessary to model tree stems and branch systems, limitations of the wave tank facilities, and scaling factors. Based on the above considerations, Froude's model law* and a linear scale of 1:5 were used to derive the following model-to-prototype relationships:

Characteristics	Dimensions	Model-Prototype Scale Relations
Length	L	$L_r = 1:5$
Area	L^2	$A_r = L_r^2 = 1:25$
Volume	L^3	$V_r = L_r^3 = 1:125$
Time	T	$T_r = L_r^{1/2} = 1:2.24$

Design of Model

4. Both 4-in.-* and 12-in.-diameter tree stems were modeled using 3-ft lengths of plastic-standard number 40-PVC pipe, Photos 1 and 2, respectively. A field survey of cottonwood trees, combined with the analysis of other available data[†,††] on trees very similar to the

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* J. C. Stevens et al., "Hydraulic Models," Manual of Engineering Practice No. 25, 1942, American Society of Civil Engineers, New York, N. Y.

** A table for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

† H. W. West and H. H. Allen, "A Technique for Quantifying Forest Stands for Management Evaluations," Technical Report M-71-9, Dec 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

†† U. S. Army Engineer Waterways Experiment Station, CE, "Plant Data Retrieval System," Computer Program (704-G9RO-238, Fortran IV), Mobility and Environmental Systems Laboratory, Vicksburg, Miss.

cottonwoods, showed the average branch diameter to be 5/8 in. and
1-1/4 in. for 4-in.- and 12-in.-diameter trees, respectively. The angle
the branches made with the stems of the trees ranged from 30 to 60 deg.
The horizontal distance measured from the center of the tree stem to the
outer limits of the branch systems averaged 4 ft and 6 ft for the 4-in.-
and 12-in.-diameter stems, respectively. On both the 4-in. and 12-in.
tree stems, there was an average vertical distance of 2-1/2 ft between
branch systems.

5. Based on these data, the PVC pipe was drilled and hardwood
dowel pins of appropriate length and diameter were inserted to produce
the two styles of branch systems that were tested (Photos 3 and 4).
Due to the high degree of variations and concentrations of tree foliage,
the plans tested did not include modeling of the tree foliage.

6. When either the 4-in. or 12-in. tree stems were tested with
or without branches, they were anchored to the test flume floor in
the pattern shown in Figure 2. The pattern was continued for the three
depths of tree stems (i.e., horizontal distance from the front row to
the last row of trees) that were tested: 140, 300, and 460 ft.

Test Facilities and Equipment

7. A portion of the L-shaped wave flume (Figure 3) was used for
all tests. The wave flume was equipped with a flap-type wave generator
capable of producing monochromatic waves of various heights and periods.
The model trees were tested in an area 106 ft long and 15 ft wide (Fig-
ure 3), and approximately 50 ft from the wave generator. Changes in
water-surface elevation (wave heights) as a function of time were
measured as they entered and exited each test depth of tree stems by
electrical parallel-wire resistance type gages. The output of these
gages was fed through an electrical amplifier-converter and then
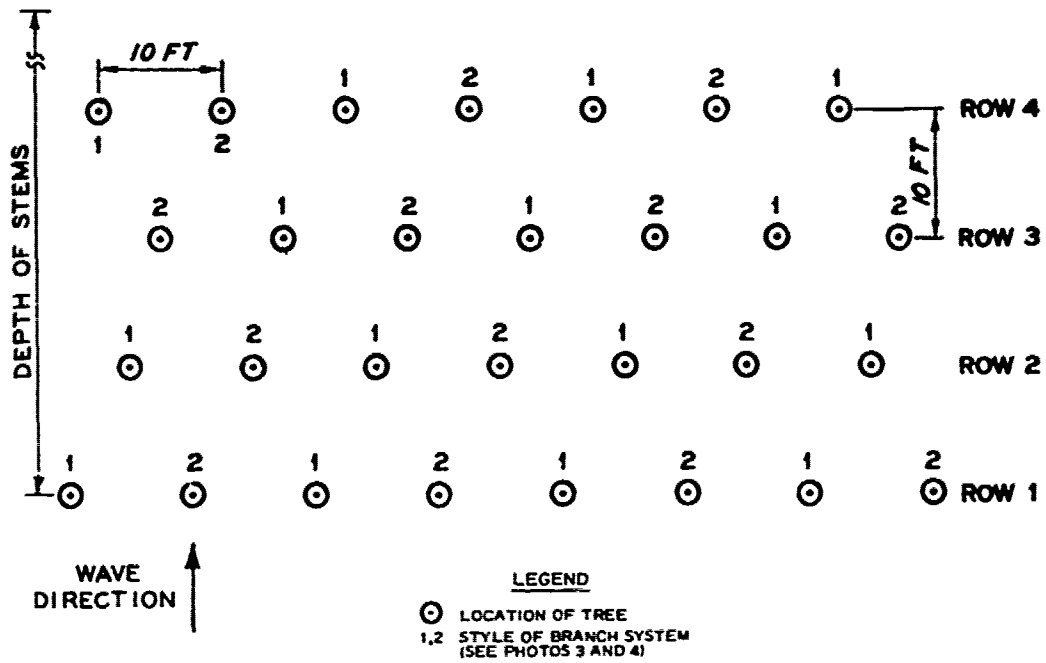recorded on chart paper by an electrically operated oscillograph.

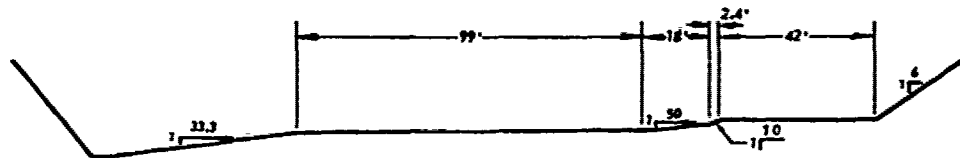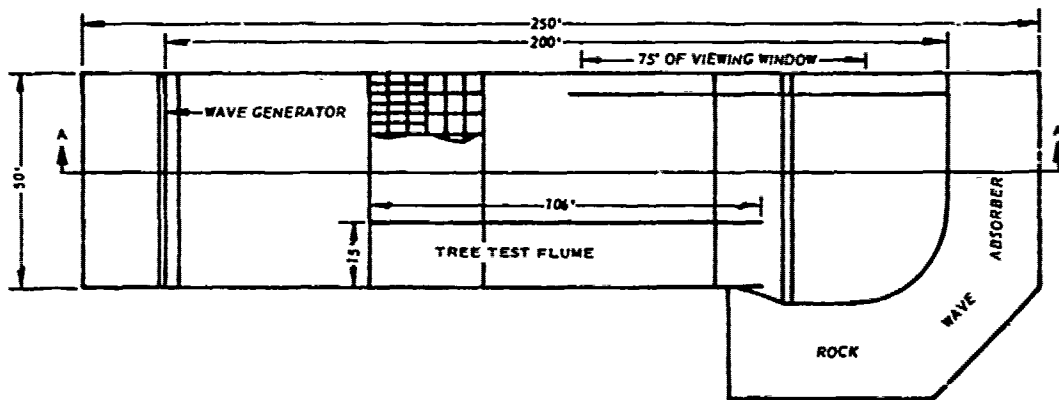Figure 2. Tree pattern and spacing. (Note: pattern repeats every four rows.)

SECTION A-A

Figure 3. L-shaped wave flume

listed in Table 1 and plotted on Plates 1 and 2. Photo 5 shows Plan 4 without water in the flume.* The two gages located in the background measured incident wave height, and the two gages in the foreground measured transmitted wave height. Plan 10, with and without water, is shown in Photos 6 and 7, respectively. The maximum depth of tree stems with branches (Plan 12) is shown with and without water in Photos 8 and 9, respectively.

10. Plans 1-6 showed very minimal wave attenuation for all three wave periods tested, but a general trend of increasing wave-height dissipation can be seen for decreasing wave period and increasing depth of tree stems. Somewhat larger wave attenuations, with the same general trend as shown by Plans 1-6, can be seen for Plans 7-12; however, the only significant decrease in wave height is shown by Plans 11 and 12 for the 2-sec wave period only.

11. In general, for the given wave conditions and designated tree pattern and spacing, wave attenuation by tree stems is not expected to exceed a maximum of about 15 percent and on the average will not exceed about 9 percent. For the same test conditions, wave attenuation through the tree branches is not expected to exceed a maximum of 45 percent and on the average will be closer to 15 percent.

12. Based on the limited tests conducted and since foliage was not represented, it is believed that results of these tests represent the lower limit of wave attenuation. Other types of trees or shrubs that have more concentrated branches may provide better wave attenuation. Also, if a feasible means were found to model the foliage, and then verify that it was modeled correctly, a much higher wave attenuation might result. It should be kept in mind, however, that unless the trees or shrubs are evergreen, the wave attenuation produced by the foliage will be lost during the late fall and winter months. The foliage could also be stripped off by wave and current action during the spring and summer months.

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* Photos 5-9 of the model were taken looking toward the wave generator.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

13. Based on the tests conducted herein, it is concluded that
wave attenuation by tree stems alone, approximately 9 percent, is not
very effective and on the average would afford only minimum protection.
Wave attenuation through the branch system without foliage increases
to about 15 percent on the average; but again, this can only be con-
sidered minimum protection. For either of the tree schemes tested,
with or without branches, and considerable depth of tree stems Plates 1
and 2) would be required to attenuate the proposed wave action
effectively.

Recommendations

14. It is realized that the model representation of the tree
schemes reported herein was limited to a first approximation and does
not represent all the detail parameters involved. For instance, foliage
and small underbrush were purposely left out due to their indeterminate
nature, which could only be verified by prototype attenuation data, and
due to their supposable secondary effects on wave attenuation during
the winter season. If prototype data existed to verify these parameters,
the model would then become a more useful tool in the evaluation process.
Although the tests reported herein were a valuable first step in under-
standing the tree attenuation process, it is recommended that further
insight be gained by conducting additional tests with foliage that are
verified by at least one set of prototype attenuation data, or that a
full-scale prototype study be conducted in which sufficient wave attenu-
ation measurements are made to quantify the tree protection concept
under varying conditions.

Table 1

Wave Transmission Coefficients, Plans 1-12

Plan Number	Stem Diameter in.	Depth of Trees ft	Branch Diameter in.	Wave Period sec	Range of Incident Wave Heights ft	Transmission Coefficient*
1	4	140	**	2.0	1.1-2.5	0.92
				2.5	1.1-3.4	0.94
				3.0	1.0-3.2	0.95
2	4	300	**	2.0	1.1-2.4	0.95
				2.5	0.9-3.0	0.98
				3.0	0.7-2.8	0.96
3	4	460	**	2.0	1.1-2.4	0.87
				2.5	1.0-3.1	0.93
				3.0	0.9-2.7	0.95
4	4	140	5/8	2.0	1.2-2.3	0.91
				2.5	0.9-3.2	0.93
				3.0	0.8-2.7	1.00
5	4	300	5/8	2.0	1.1-2.2	0.88
				2.5	0.9-2.9	0.94
				3.0	0.8-2.6	0.96
6	4	460	5/8	2.0	1.1-2.3	0.91
				2.5	1.0-3.0	0.92
				3.0	0.9-2.5	0.90
7	12	140	**	2.0	1.2-2.7	0.82
				2.5	1.0-3.3	0.95
				3.0	1.0-3.0	0.95
8	12	300	**	2.0	1.1-2.4	0.87
				2.5	1.0-3.2	0.97
				3.0	0.9-3.1	0.93
9	12	460	**	2.0	1.1-2.9	0.83
				2.5	0.9-2.9	0.92
				3.0	0.9-2.7	0.94
10	12	140	1-1/4	2.0	1.1-2.4	0.76
				2.5	0.9-3.0	0.91
				3.0	0.8-2.8	0.89
11	12	300	1-1/4	2.0	1.1-2.3	0.67
				2.5	0.9-3.1	0.87
				3.0	0.8-3.0	0.90
12	12	460	1-1/4	2.0	1.2-2.3	0.54
				2.5	0.9-3.2	0.85
				3.0	0.9-2.8	0.83

* Does not include wave attenuation due to flume wall and floor friction.
** Without branches.
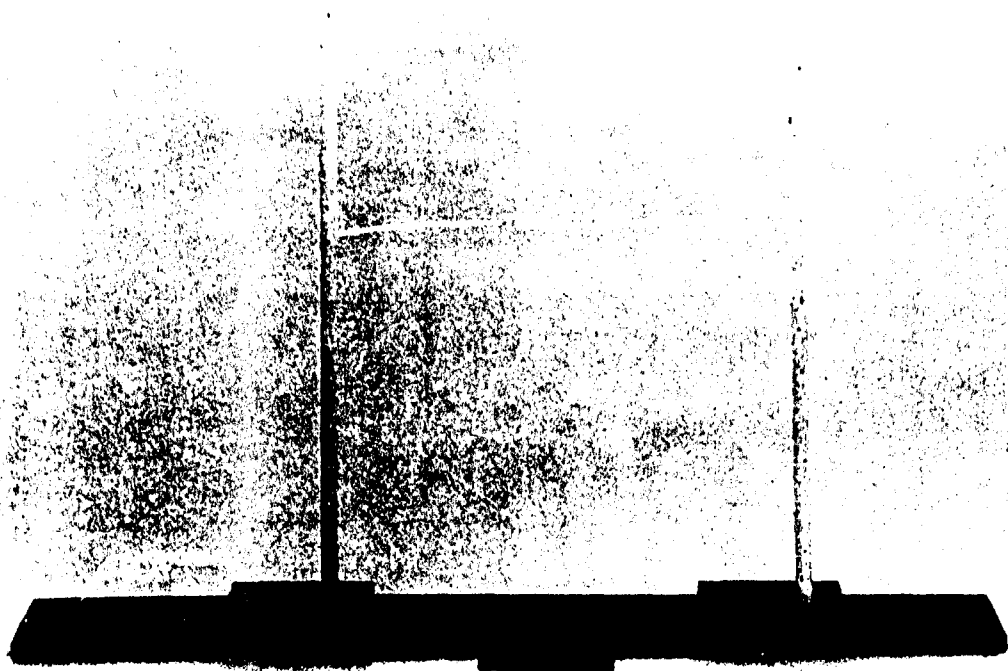
Photo 1. 4-in.-diameter stems without branches, used in Plans 1-3
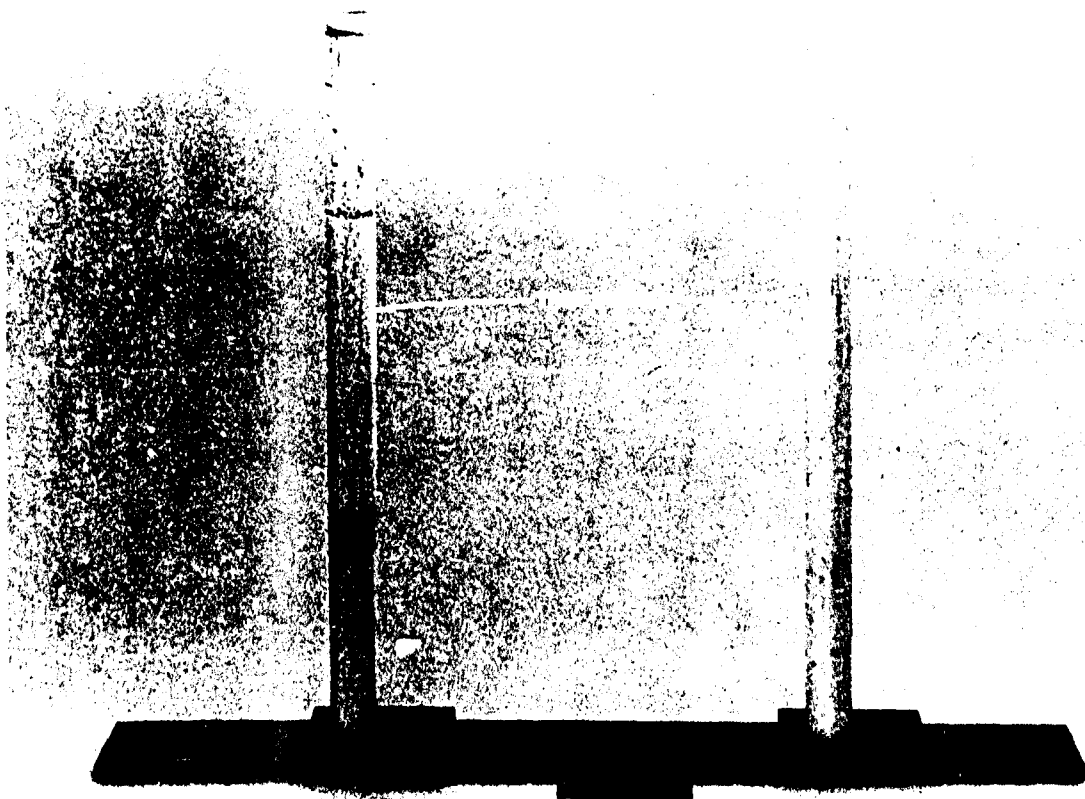
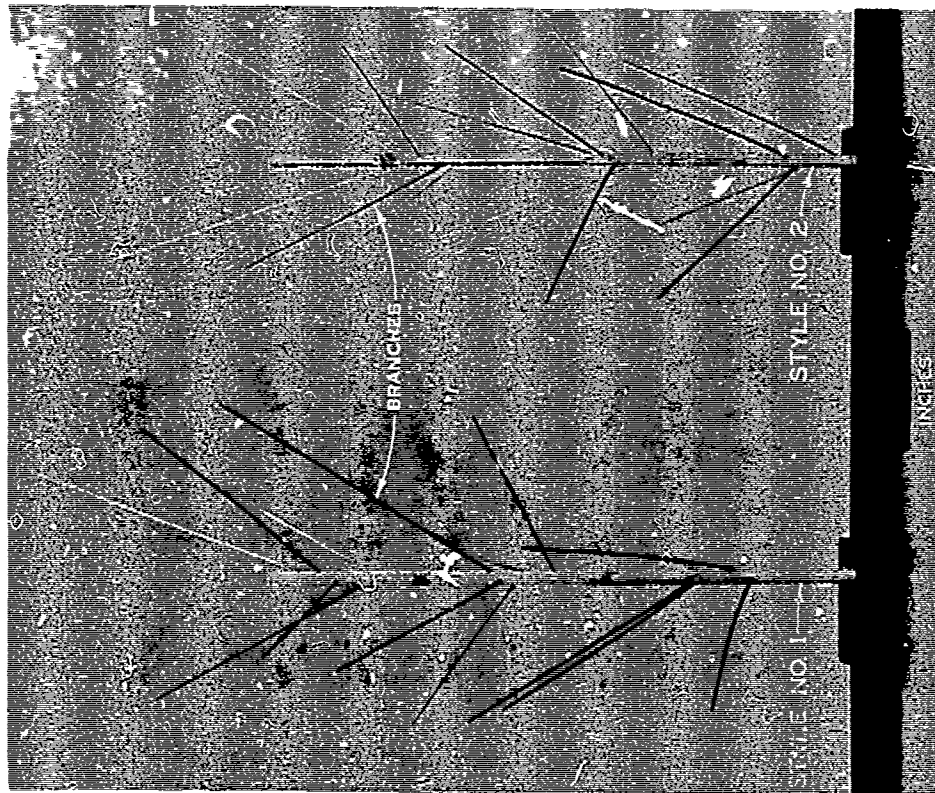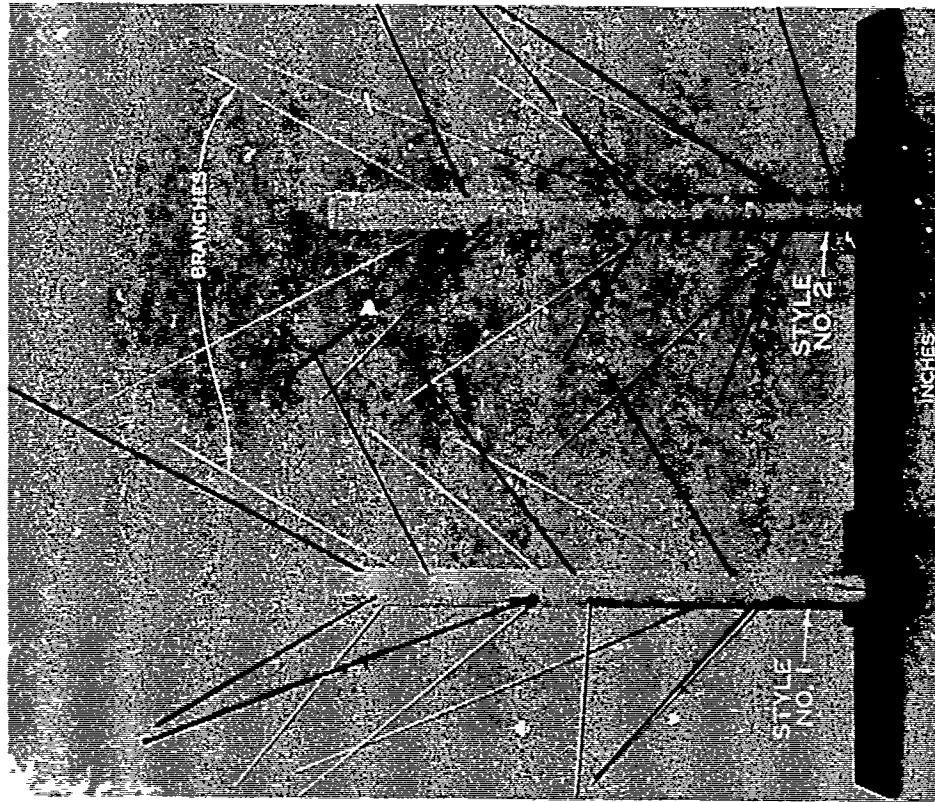Photo 2. 12-in.-diameter stems without branches, used in Plans 5-7

Photo 4. 12-in.-diameter stems with 1-1/4-in. branches. Styles 1 and 2 used in Plans 10-12

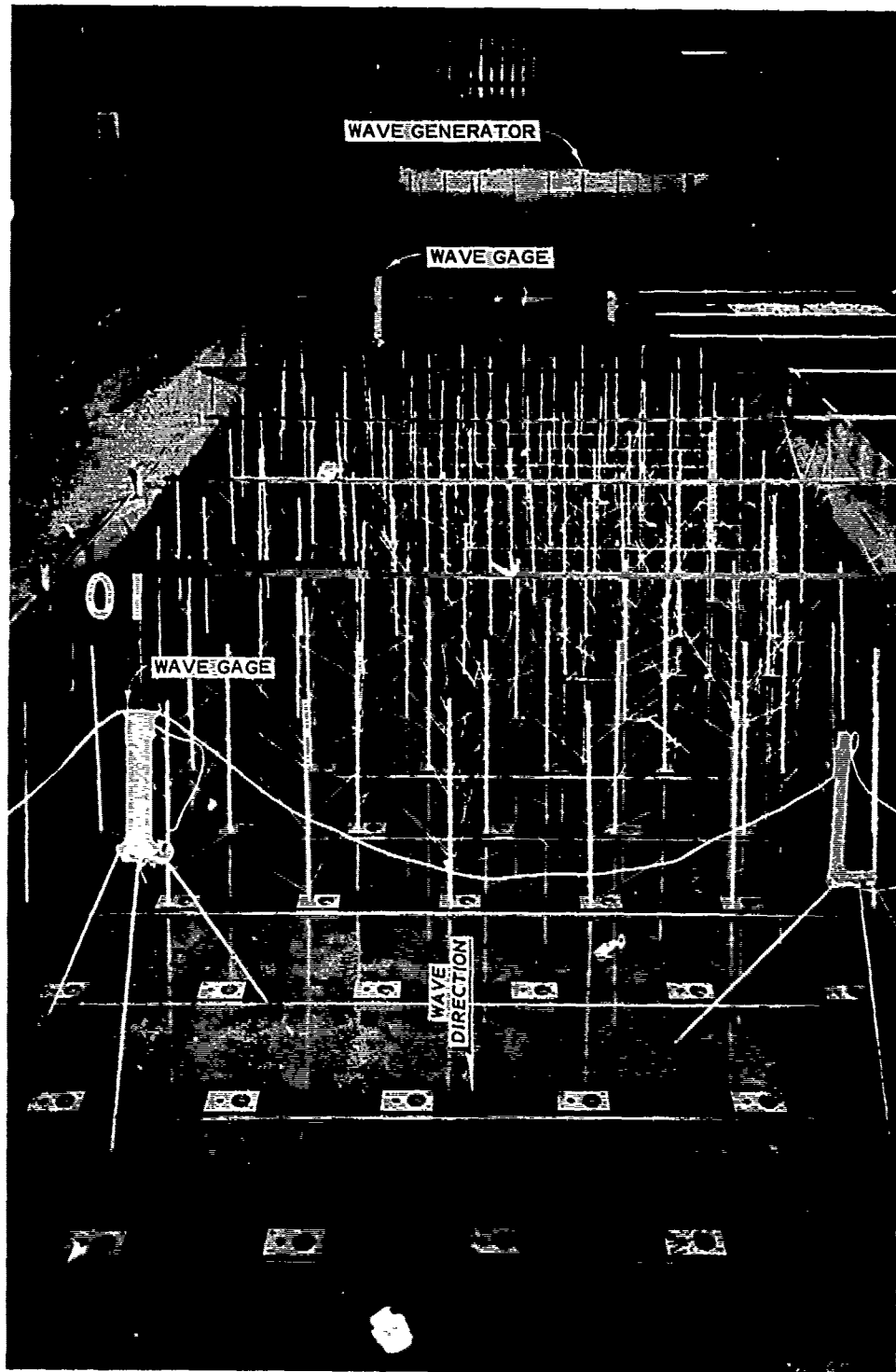Photo 3. 4-in.-diameter stems with 5/8-in. branches. Styles 1 and 2 used in Plans 4-6

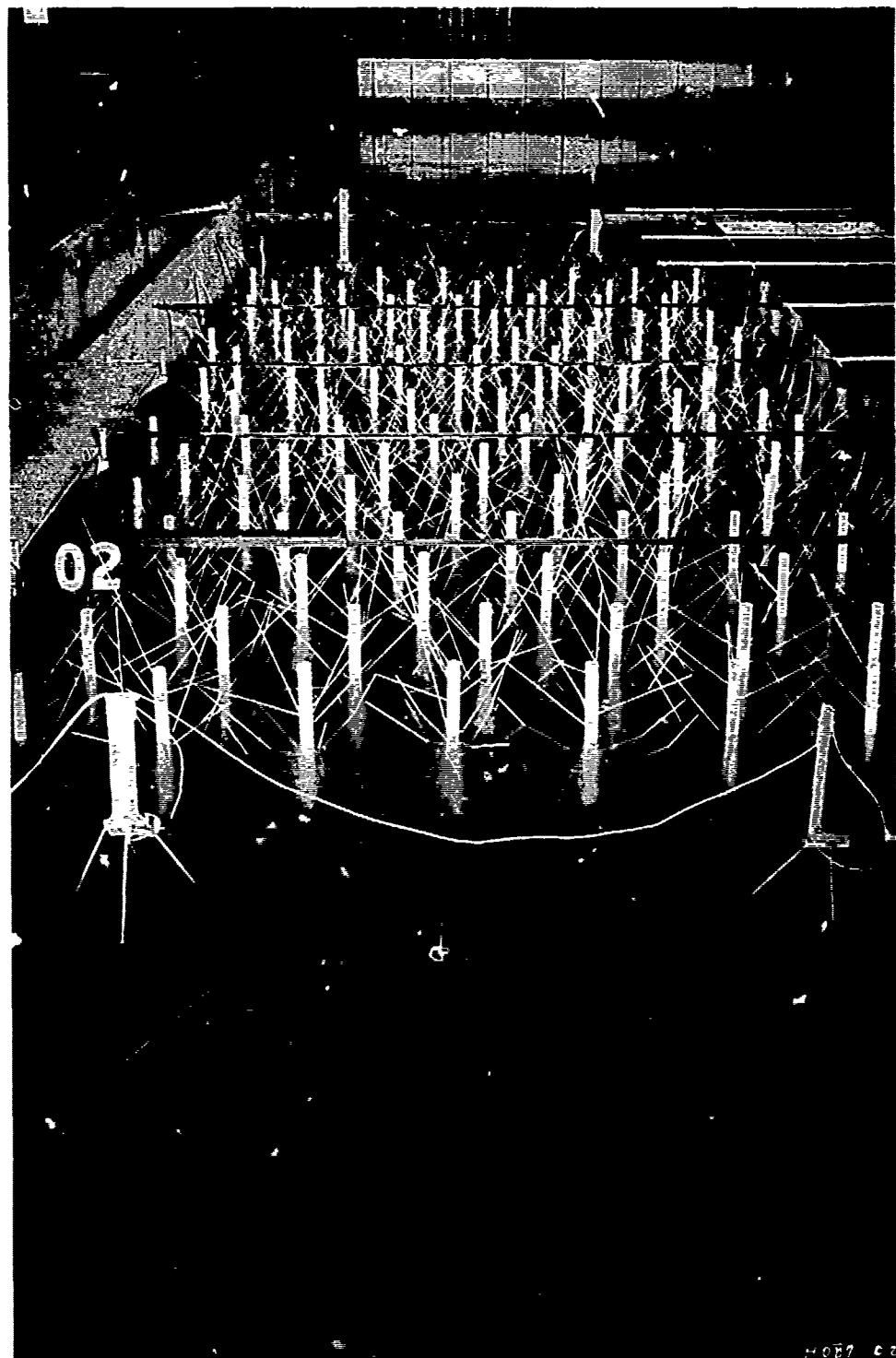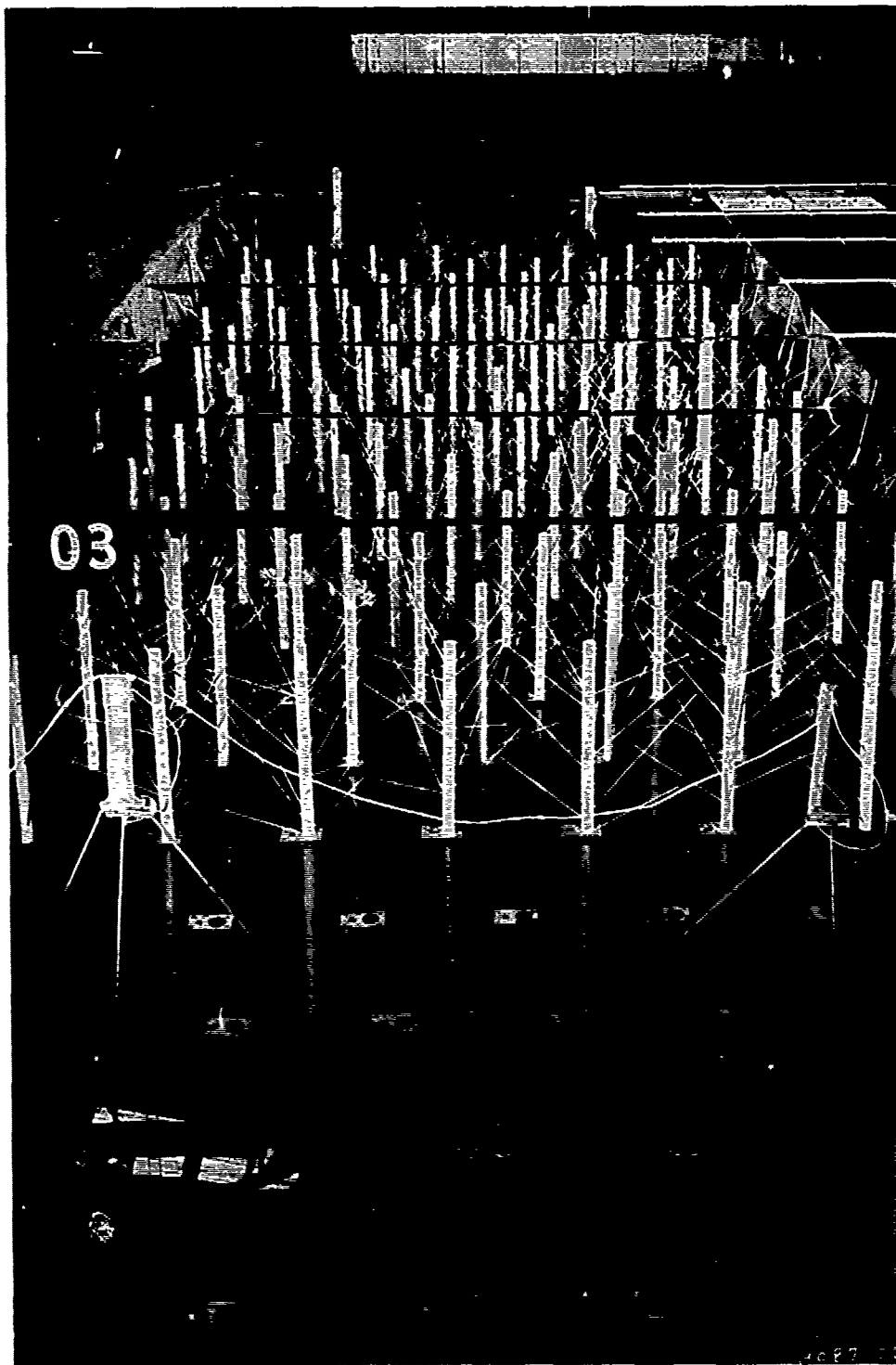Photo 5.   Plan 4, 4-in.-diameter stems with 5/8-in. branches
without water in flume

Photo 6. Plan 10, 12-in.-diameter stems with 1-1/4-in. branches
with model water depth of 2.0 ft

Photo 7.   Plan 10, 12-in.-diameter stems with 1-1/4-in. branches
without water in flume

Photo 8.   Plan 12, 12-in.-diameter stems with 1-1/4-in. branches
with model water depth of 2.0 ft

Photo 9. Plan 12, 12-in.-diameter stems with 1-1/4-in. branches
without water in flume
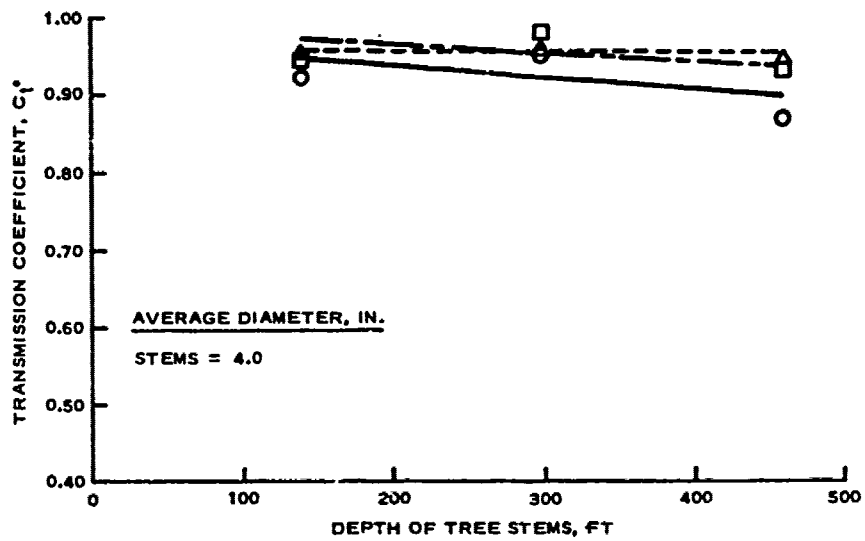
a. PLANS 1-3
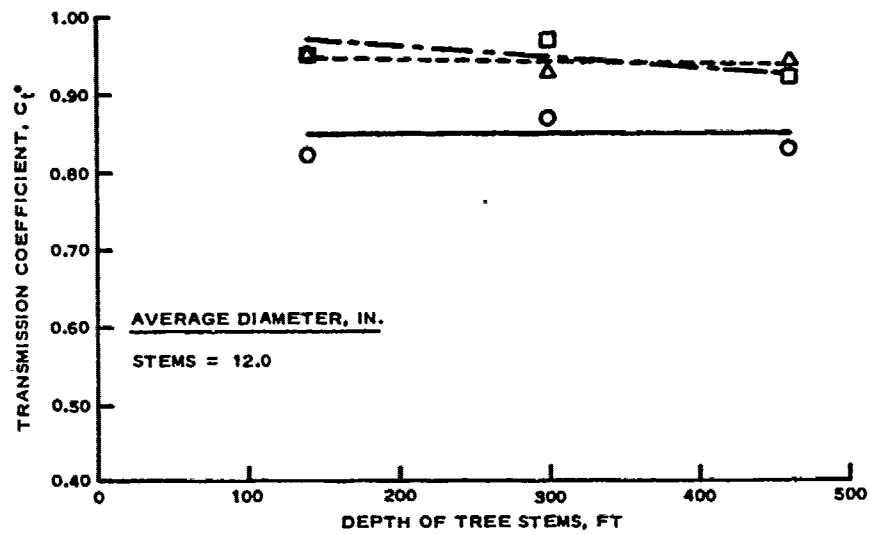
b. PLANS 7-9

$\bullet$ C_t = TRANSMITTED/INCIDENT WAVE HEIGHT

WAVE PERIOD, SEC

o———o	2.0
□– –□	2.5
△– – –△	3.0
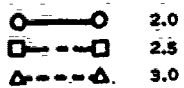
TRANSMISSION COEFFICIENT
VERSUS DEPTH OF TREE STEMS
WITHOUT BRANCHES

PLATE 1
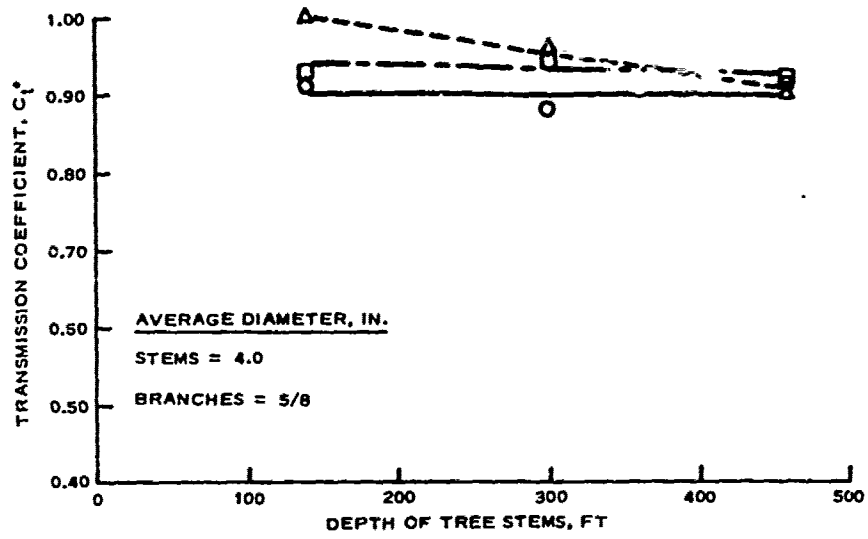
a. PLANS 4 - 6

b. PLANS 10 - 12

• C_t = TRANSMITTED/INCIDENT WAVE HEIGHT

WAVE PERIOD, SEC

o——o	2.0
□---□	2.5
△----△	3.0

TRANSMISSION COEFFICIENT
VERSUS DEPTH OF TREE STEMS
WITH BRANCHES

PLATE 2