DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

BEACH EROSION BOARD

OFFICE OF THE CHIEF OF ENGINEERS

LABORATORY DATA ON WAVE RUN-UP AND OVERTOPPING ON SHORE STRUCTURES

TECHNICAL MEMORANDUM NO. 64

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OCTOBER 1955

FOREWORD

A need for more adequate design data on wave run-up and overtopping of shore structures has long been evident, most such structures being designed to meet run-up and overtopping requirements by rule of thumb rather than on a sound, factual basis. The total height of run-up determines the elevation to which a structure must be raised if flooding is to be prevented on the landward side; if the requisite height is not economically (or otherwise) feasible, a lower structure must be designed with resulting overtopping during storm periods. The amount of this overtopping is important not only for the design of a safe structure, but also from adequate design of flood protection and drainage behind the structure. Prior to the initiation of a comprehensive series of tests by the Beach Erosion Board in 1952, essentially no quantitative data was available on this subject; since then, however, a considerable number of tests have been run, and this report presents tabulated data obtained over the course of the experiments. Analysis of the data has not yet been completed, but will be presented in a future report. Also included in the present report are some additional data obtained by the Waterways Experiment Station for the Jacksonville District of the Corps of Engineers in connection with the design of Lake Okeechobee levees.

The present report was prepared by Thorndike Saville, Jr., Assistant Chief of the Research Division of the Beach Erosion Board. At the time the report was prepared the Research Division was under the supervision of J. M. Caldwell, Chief of the Division; the technical staff of the Board was under the general supervision of Brigadier General Theron D. Weaver, President of the Board.

The experimental program was developed by the Research Division of the Board, and carried out under their general instructions by personnel of the Waterways Experiment Station of the Corps of Engineers at Vicksburg, Mississippi. Mr. Robert Jackson was the project engineer in charge of the actual experimentation, under the general supervision of Mr. R. Y. Hudson, Chief of the Wave Action Section of the Hydraulics Division. Colonel C. H. Dunn was Director of the Experiment Station during this period.

The program was supported jointly from Beach Erosion Board Development funds and from funds from the Civil Works Investigation Program of the Office of the Chief of Engineers, under Project CW 831 "Structural Design of Shore Structures". The Jacksonville District program was supported by funds from the Central and Southern Florida Project.

LABORATORY DATA ON WAVE RUN-UP AND OVERTOPPING ON SHORE STRUCTURES

by
Thorndike Saville, Jr.
Research Division, Beach Erosion Board

A need for more adequate design data on wave run-up and overtopping of shore structures has long been evident, most protective structures along the shores of rivers, lakes, reservoirs, and the oceans being designed to meet run-up and overtopping requirements by rule of thumb rather than on a sound factual basis. The amount of run-up on a given structure determines the height to which the structure must be raised if flooding is to be prevented on the landward side; these crest elevations have usually been determined by applying a rather arbitrarily selected run-up - wave height ratio (R/H). A value of R/H equal to 1.5 has been most frequently used, although values as low as 0.9 and as high as 2.0 have been suggested for particular designs. It has been generally recognized that the correct value would depend on the type of structure, the depth at its toe, and the wave characteristics, but sufficient data has not been available to accurately determine these relationships. If it becomes economically infeasible or otherwise impracticable to build a structure of the requisite height (beach cottage owners, for example, generally disapprove of seawall designs so high as to obstruct their view of the water), a lower structure must be designed, which results in overtopping during storm periods. The amount of overtopping is important not only for the design of a safe structure (i.e., prevention of failure from back face erosion, excess water pressure, seepage, etc.), but also from the standpoint of the prevention of flooding and the design of an adequate drainage and pumping system to remove the overtopping water. Once again, practically no quantitative data has been available to enable an adequate prediction of the volume of overtopping water for various wall types and wave conditions.

Recognizing the lack of basic data, the Beach Erosion Board, as a part of its general research program on factors basic to shore protection and the design of shore structures, initiated in 1952 a test program of a generalized nature on wave run-up and overtopping. The tests have been carried out at the Waterways Experiment Station of the Corps of Engineers, at Vicksburg, Mississippi in accordance with a test schedule prepared by the Board. Some additional tests were also carried out for the Jacksonville District of the Corps of Engineers to aid specifically in the design of the new levee system around Lake Okeechobee, Florida and the adjacent water conservation pools.

A preliminary analysis of some of the overtopping data on the vertical wall structure has been presented by Saville and Caldwell[(1)*]

*Numbers in parentheses indicate references on page 4.

and an analysis of the additional data is now under way. However, as complete analysis of the data will require considerable time, the basic data are presented herein without the analysis, to permit immediate usage of the test results by the designer in the field. The designer may be able to interpolate and extrapolate between the tabulated data to obtain a better design value for his particular problem, even though a complete analysis of the data is not yet available. Accordingly the data obtained are tabulated herein, but with no attempt at analysis or to draw conclusions; a further report containing analysis and conclusions will be published at a later date, and will include graphs from which design data may be taken directly.

The test program for the Beach Erosion Board was carried out in a concrete wave flume 120 feet long, 5 feet wide, and 5 feet deep (Figure 1). Waves were generated by a plunger type wave machine in which the wave period could be regulated by varying the speed of the motor, and the wave height by varying the eccentricity of the plunger arm and hence the depth of penetration of the plunger (Figure 2). Waves of known characteristics were propagated against the test structure at the opposite end of the tank (Figures 3 and 4). The volume of overtopping water was measured in a calibrated tank located immediately behind the seawall. The tank was so arranged that the overtopping water could be diverted either into the measuring tank or beyond into a waste area, so as to permit measurement of amount of overtopping for any particular wave group selected. In order to permit a stable condition to obtain before measurements were taken, the overtopping water from the first three or four waves was wasted; measurements were then taken on the next six or seven waves, but were, in any case, stopped before reflected waves from the structure could reach the generator and return to the structure. The generator was then shut down, the water quieted, and the measurements repeated for the same set of wave conditions. The results, therefore, represent averages of at least two, and frequently three, different sets of measurements. There was, in general, little difference in measurements between runs, the measurements having an average deviation of about 8 to 10 percent. In addition, high-speed motion pictures (64 frames per second) were taken of most of the tests.

For the Beach Erosion Board program, the structures tested were a vertical wall, a curved wall (based on the Galveston seawall section), a curved wall with recurvature at the top, smooth slopes of 1 on $1\frac{1}{2}$ and 1 on 3, a step-faced wall of 1 on $1\frac{1}{2}$ slope, and a riprap faced wall of 1 on $1\frac{1}{2}$ slope. Figures 5 a to g show the particular characteristics of the various walls. All structures always had the same crest width regardless of the crest elevation of the structure. The tests in this program were made with as many as three different depths of water at the structure toe, and all were fronted by a 1 on 10 beach slope down to the level portion of the tank. In addition the curved wall was tested with a 1 on 25 slope fronting the wall.

Run-up values were obtained by increasing the height of the structure sufficiently to prevent any overtopping, and then obtaining the vertical height of run-up by visual observation against a grid system attached to the glass panel alongside the structure. Run-up values reported are maximum values of run-up of solid water, and are the average of measurements from four to six tests.

For convenience in visualizing the quantitative application of the data contained herein, wave characteristics, wall dimensions, run-up, and overtopping are presented as prototype equivalents as though the model were a 1:17 undistorted scale model. The time and velocity scales are then 1:4.1, and the volume scale is 1:4900. The run-up data obtained in these tests are given in Table 1, and the overtopping data in Table 2. The overtopping data are also presented graphically in Figures 6a to q. The curves on Figures 6a to q are a best plot through the plotted points (not shown) from the data.

The additional tests made for the Jacksonville District involved smooth slopes of 1 on 2, 1 on 3, 1 on 4, 1 on 6, and 1 on 10, fronted by a 1 on 10 beach slope; a 1 on 3 and 1 on 6 slope with various berm widths at the still water level; and a composite section of 1 on 6 or 1 on 10 top section with a 1 on 3 lower section. Figures 7 and 8 show the characteristics of these test structures. These tests were conducted in a smaller wave flume at the Waterways Experiment Station, the flume being some 70 feet long, reducing from a 4-foot width and 2.9-foot depth at the generator to a 1-foot width and 1.6-foot depth at the test end to permit generation of higher and steeper waves at the test section than would ordinarily be available with the tank. The wave generator was of the flap type, wave period being controlled by setting the speed of the motor, and wave height by the eccentricity of the flap arm. The tests were conducted as a 1:30 undistorted scale model, and the data are tabulated herein in prototype size to facilitate use and comparison with the other data. The run-up data obtained are given in Table 3, and the overtopping data in Table 4. In comparing with these data it should be noted that the wave heights for the Beach Erosion Board tests are referred to deep water, but those for the Jacksonville tests are referred to the depth at the beach toe (usually 25 feet).

Some further data on wave run-up and overtopping have been presented by Granthem[2] and Sibul[3], which may be used to supplement the data contained herein to obtain design figures.

REFERENCES

1. Saville, T., Jr., and J. M. Caldwell (1953). Experimental Study of Wave Overtopping on Shore Structures, Proc. Minnesota International Hydraulics Convention, International Association for Hydraulic Research.

2. Granthem, K. N. (1953). Wave Run-up on Sloping Structures, Trans. Amer. Geophysical Union, Vol. 34, No. 5.

3. Sibul, O. (1955). Flow Over Reefs and Structures by Wave Action, Trans. Amer. Geophysical Union, Vol. 36, No. 1.

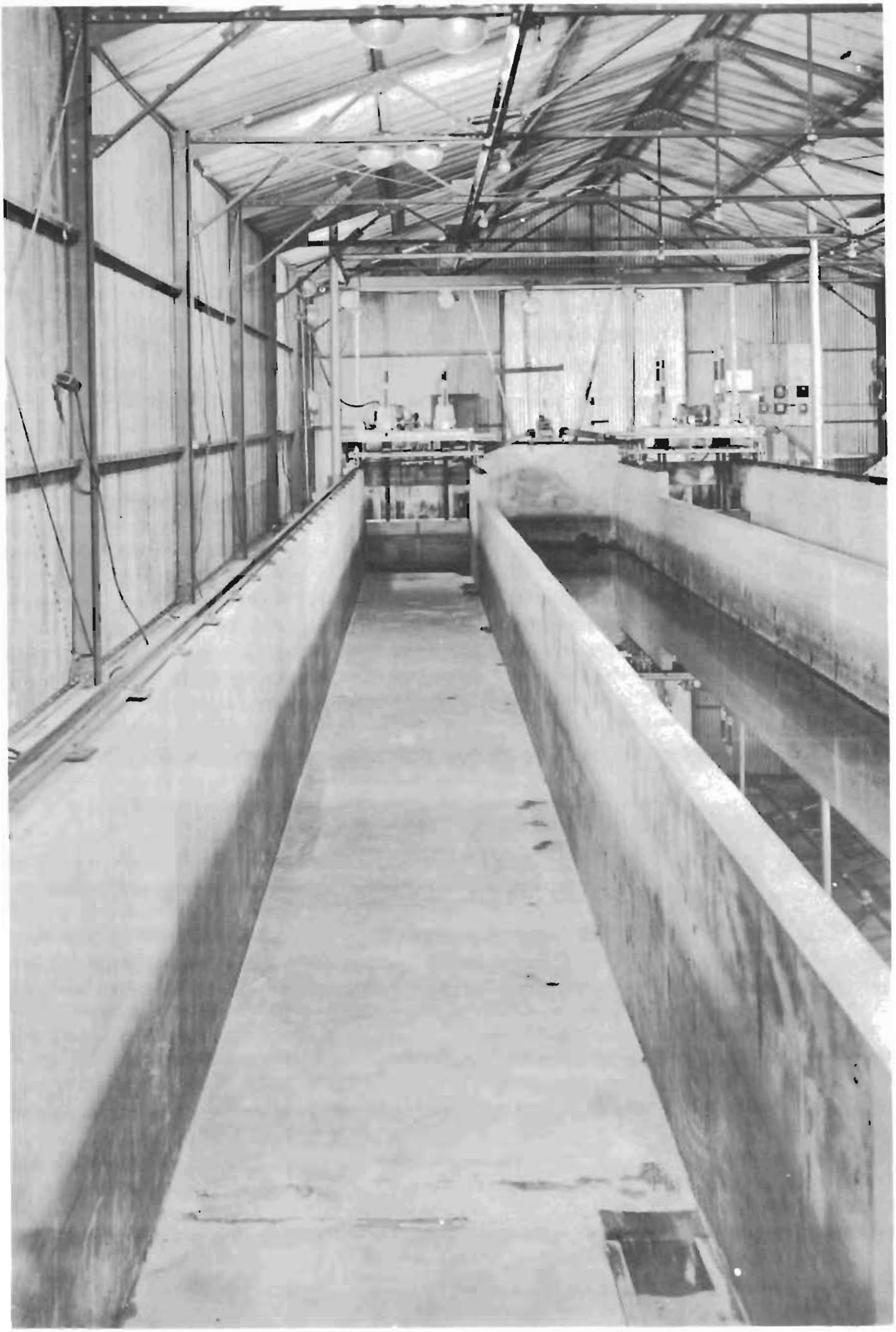


FIGURE 1. WAVE FLUME AND GENERATORS

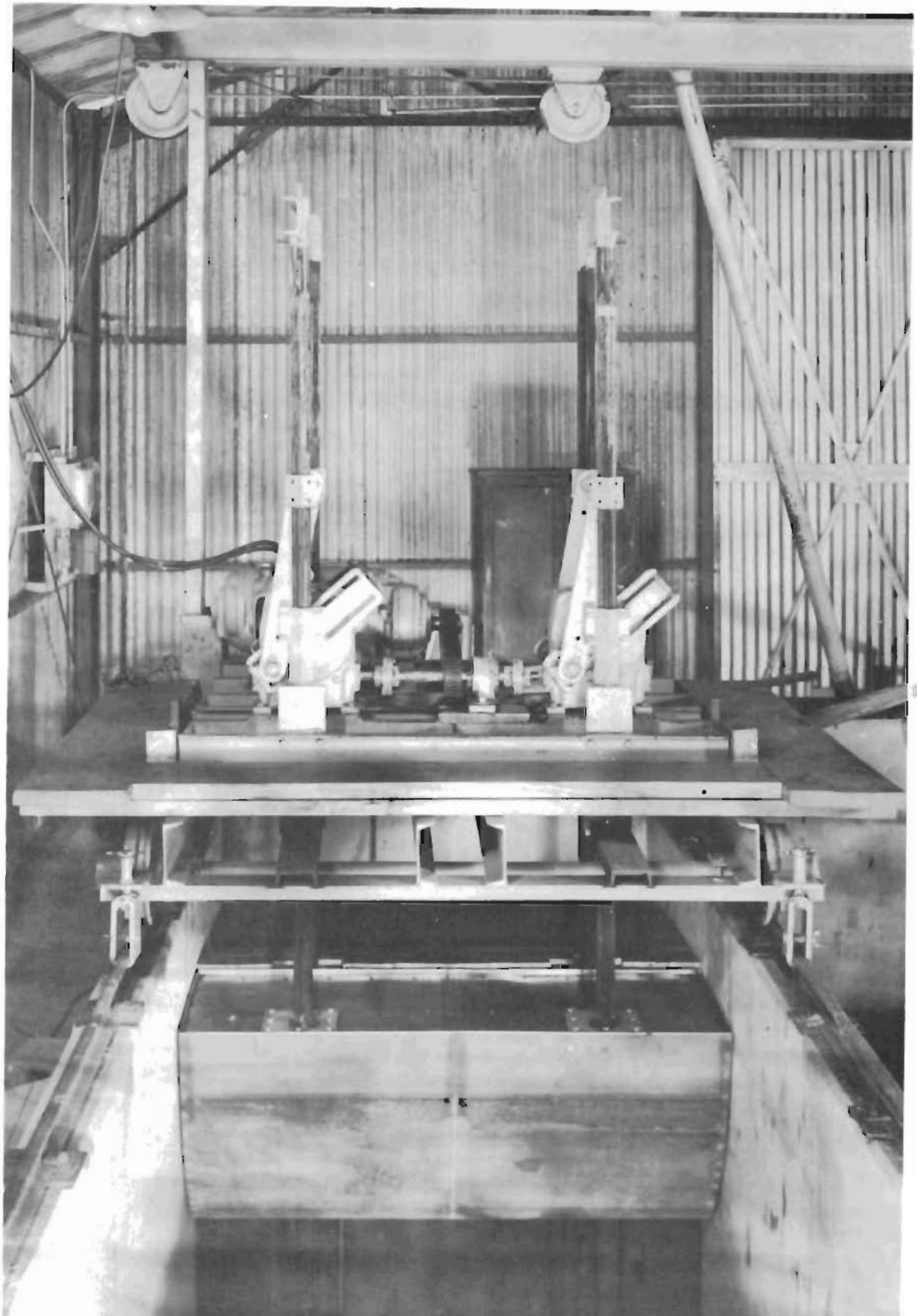
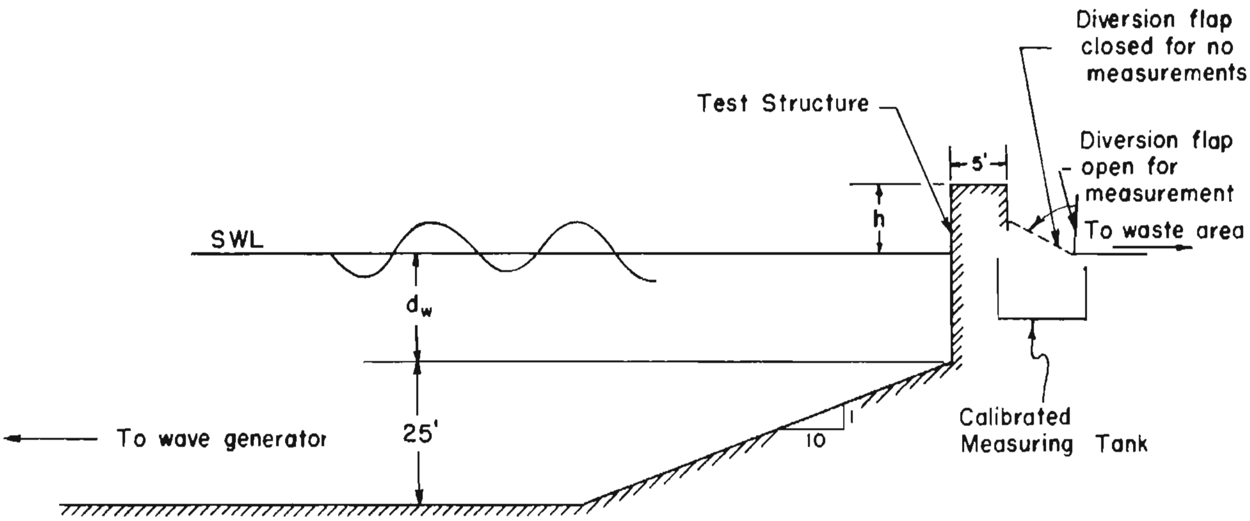


FIGURE 2. WAVE GENERATOR

FIGURE 3. BEACH SLOPE AND VERTICAL WALL TEST SECTION

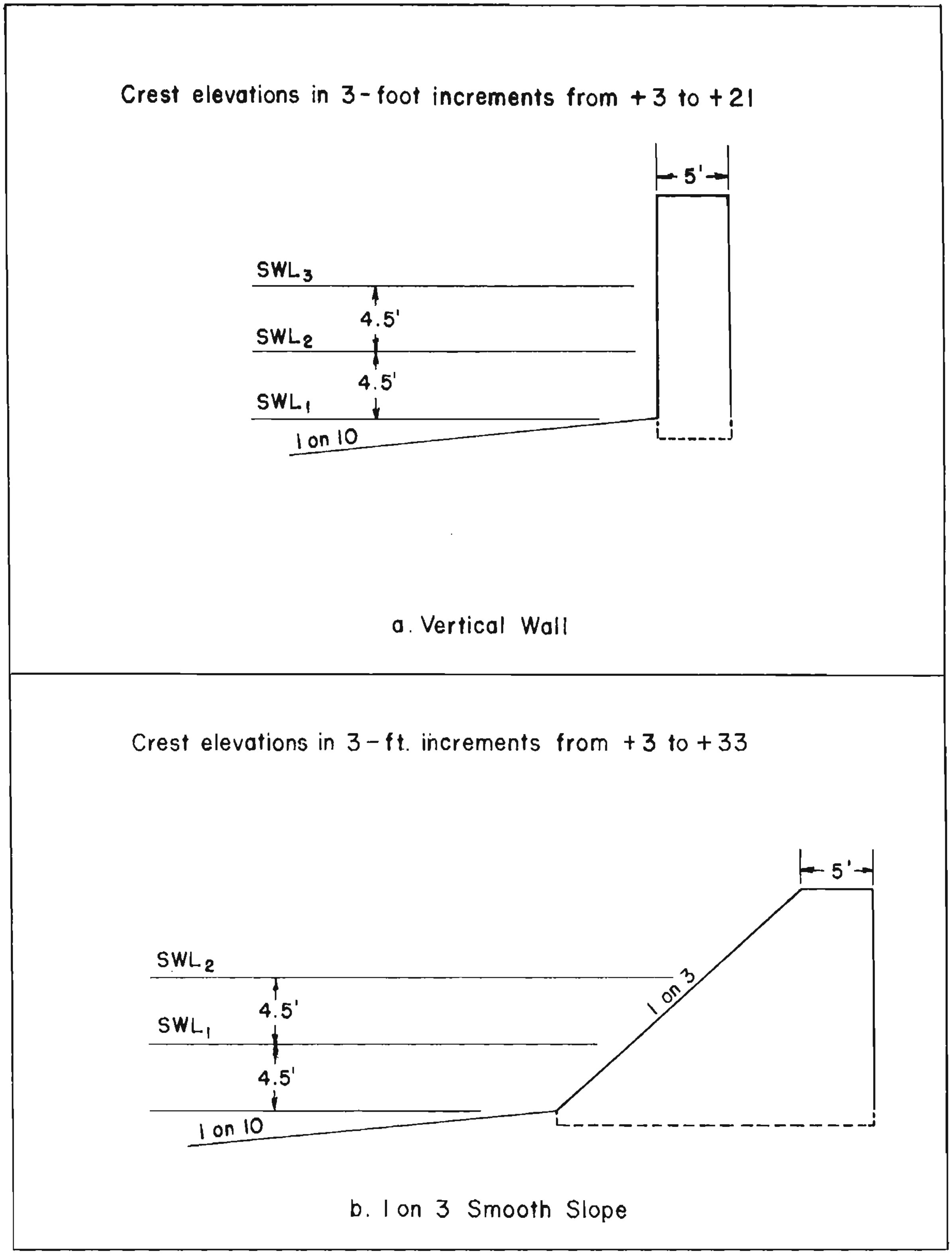


Structure test conditions

d_w = 0, 4.5, 9.0 ft.

h = 3, 6, 9, 12, etc. ft., increasing in 3-foot increments to height sufficient to prevent all overtopping

FIGURE 4 · THE TEST SET UP



a. Vertical Wall

b. 1 on 3 Smooth Slope

FIGURE 5a,b · ELEMENTS OF TEST SECTIONS

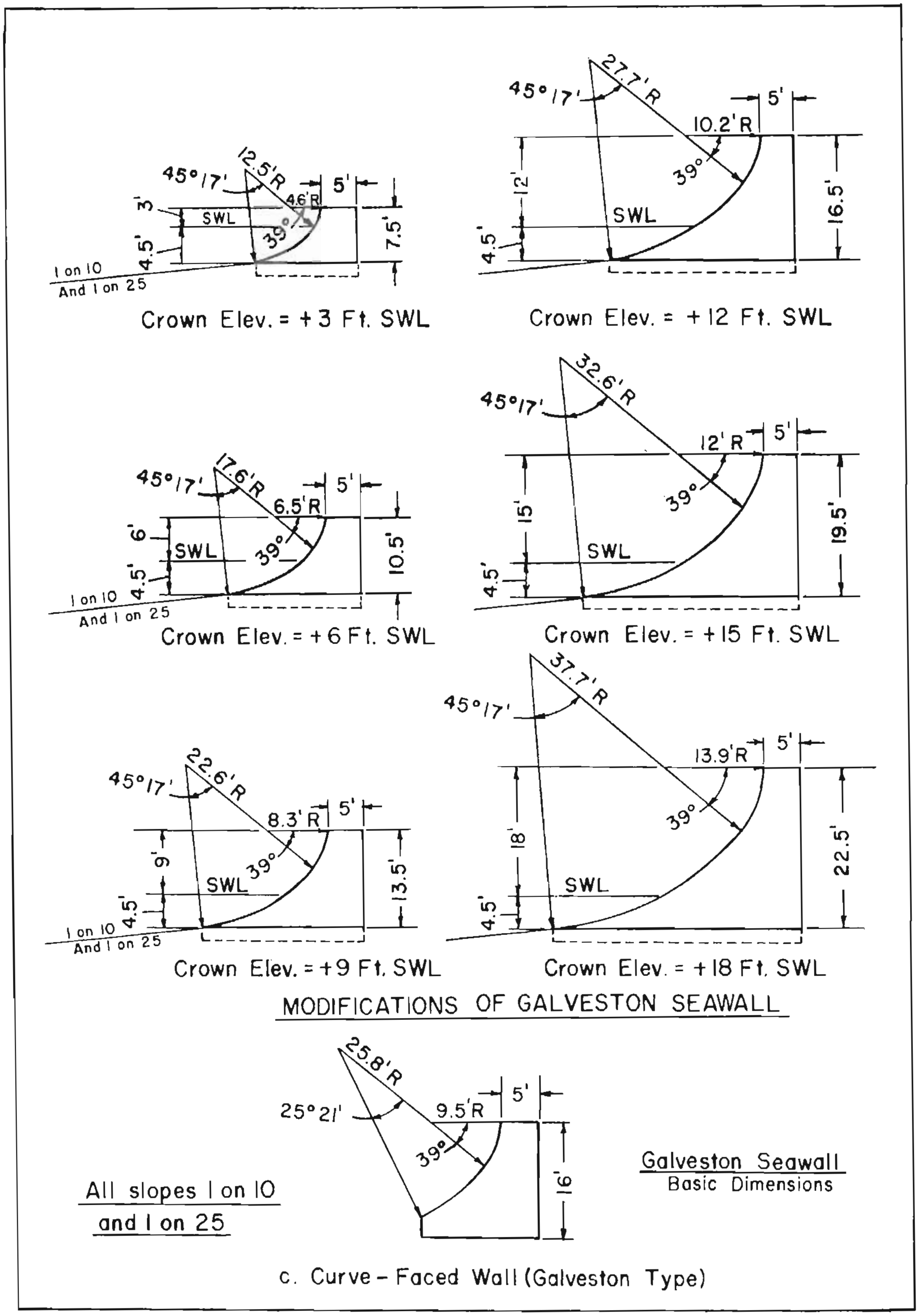
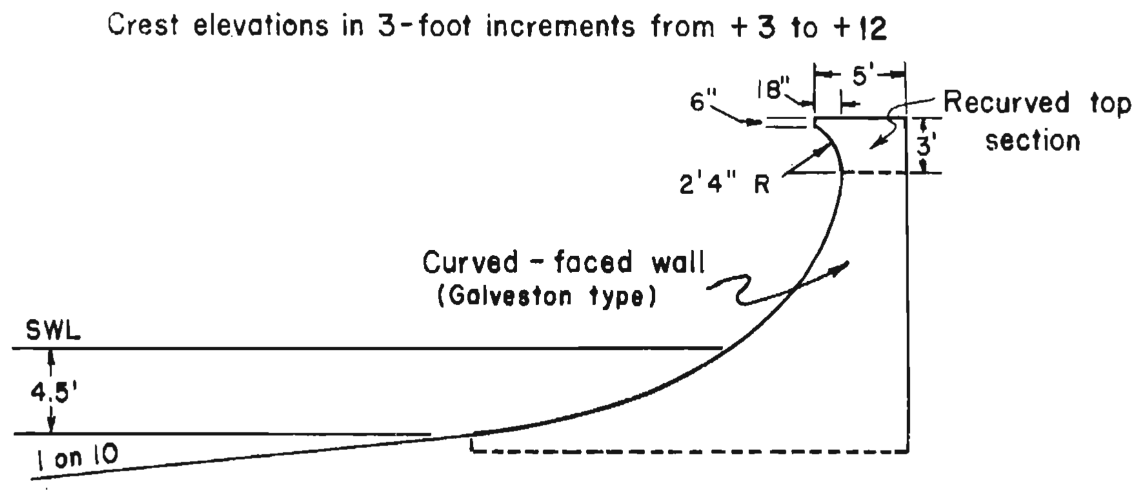
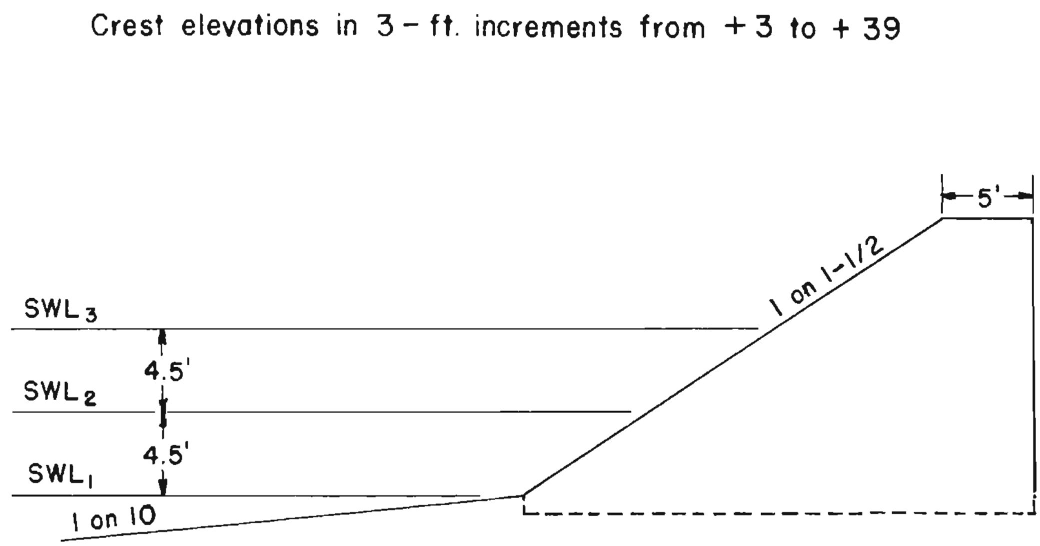


FIGURE 5c · ELEMENTS OF TEST SECTIONS

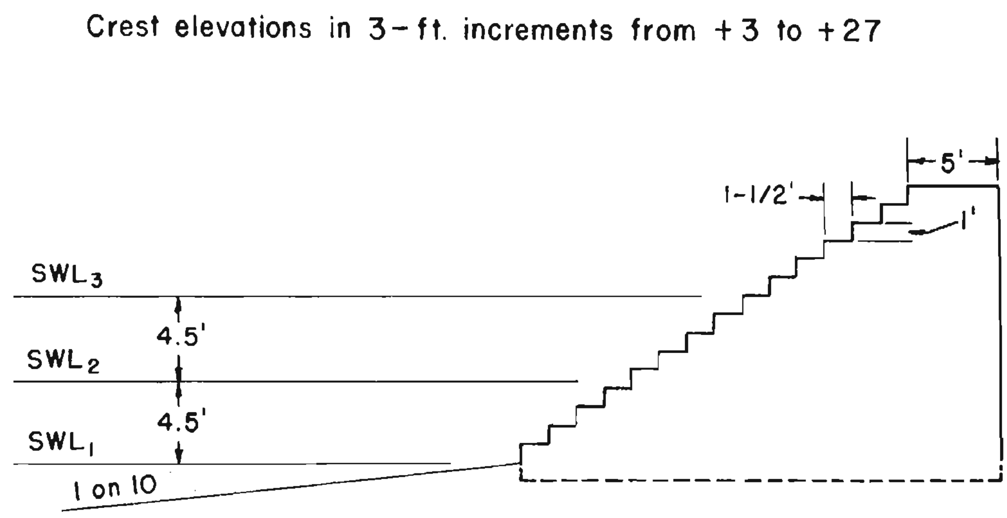


d. Recurved Wall

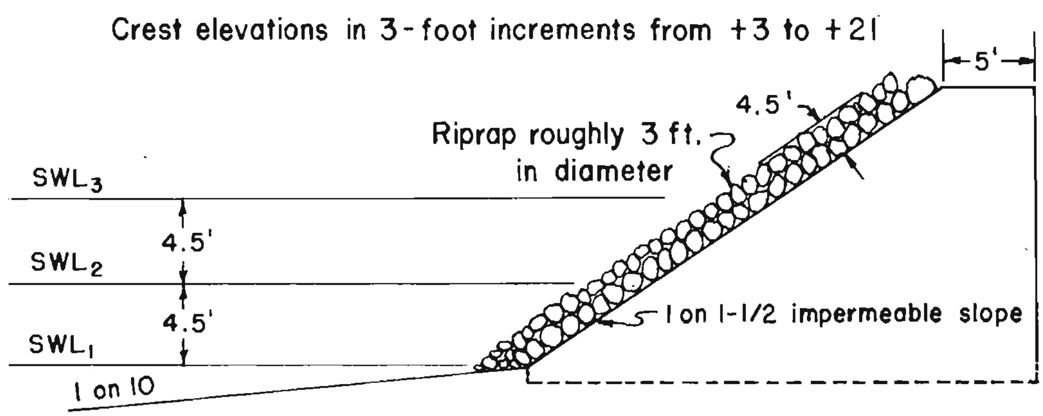


e. 1 on 1-1/2 Smooth Slope

FIGURE 5 d,e · ELEMENTS OF TEST SECTIONS

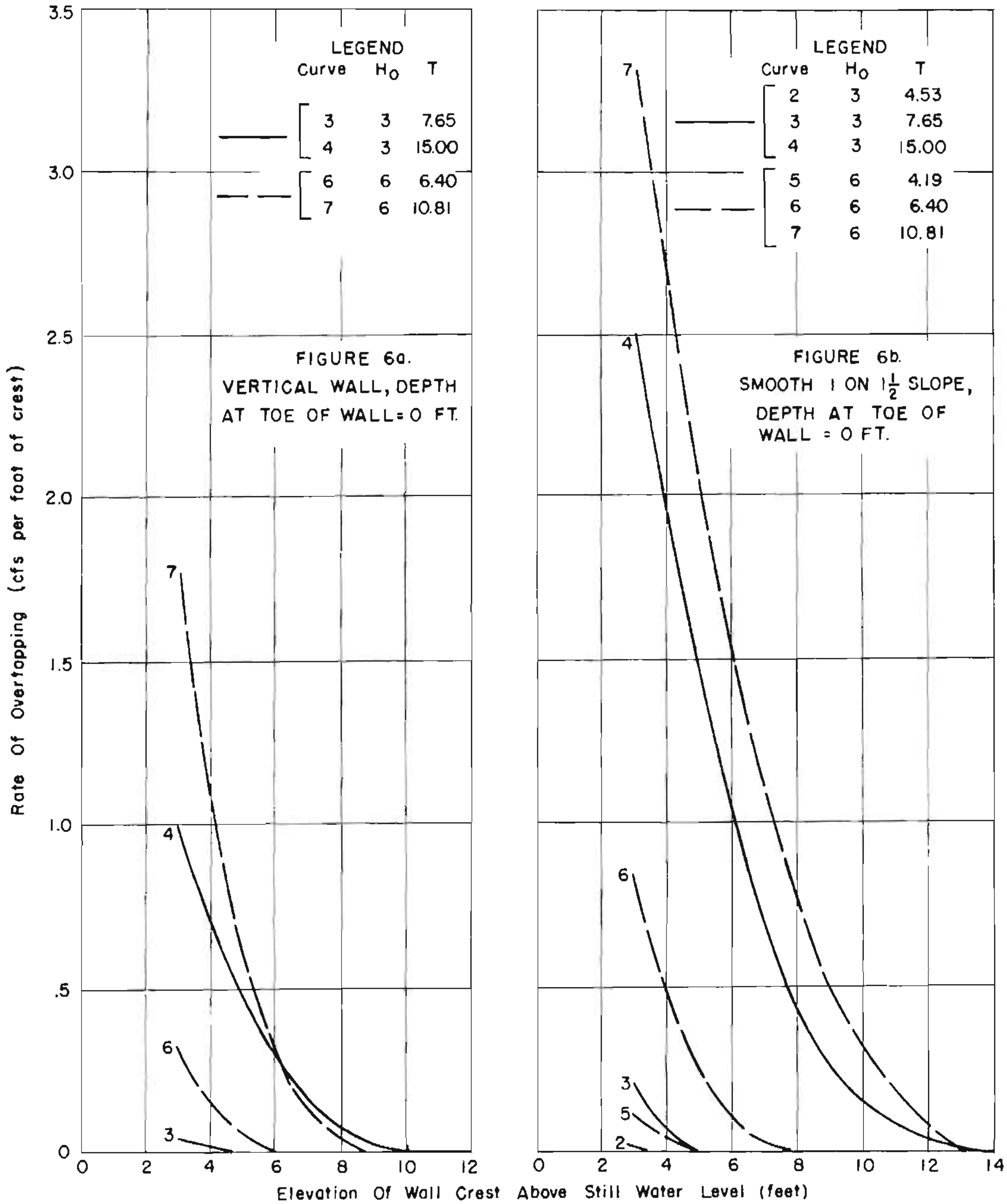


f. 1 on 1-1/2 Slope, Step-Faced Wall

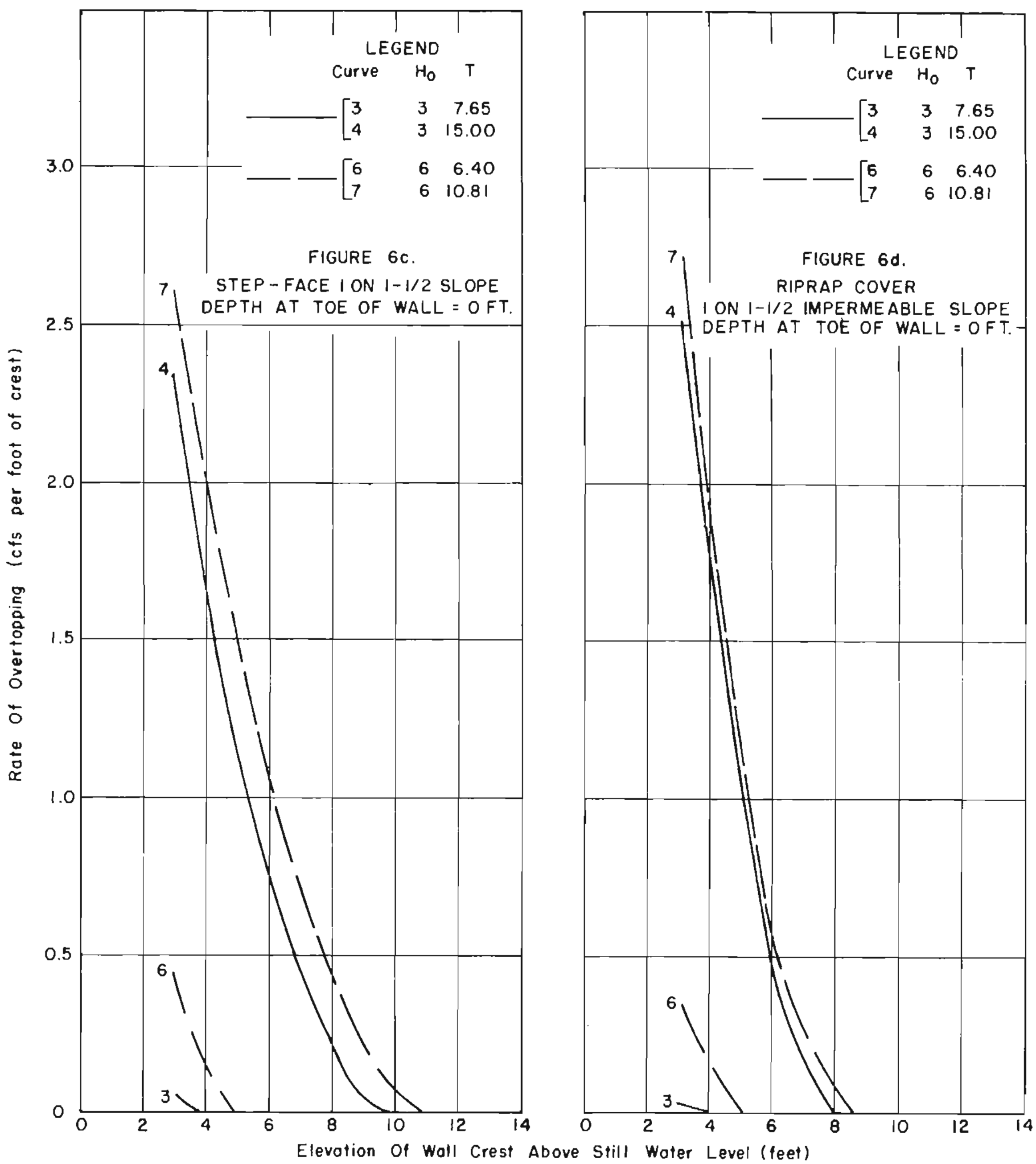


g. 1 on 1-1/2 Slope, Riprap Cover

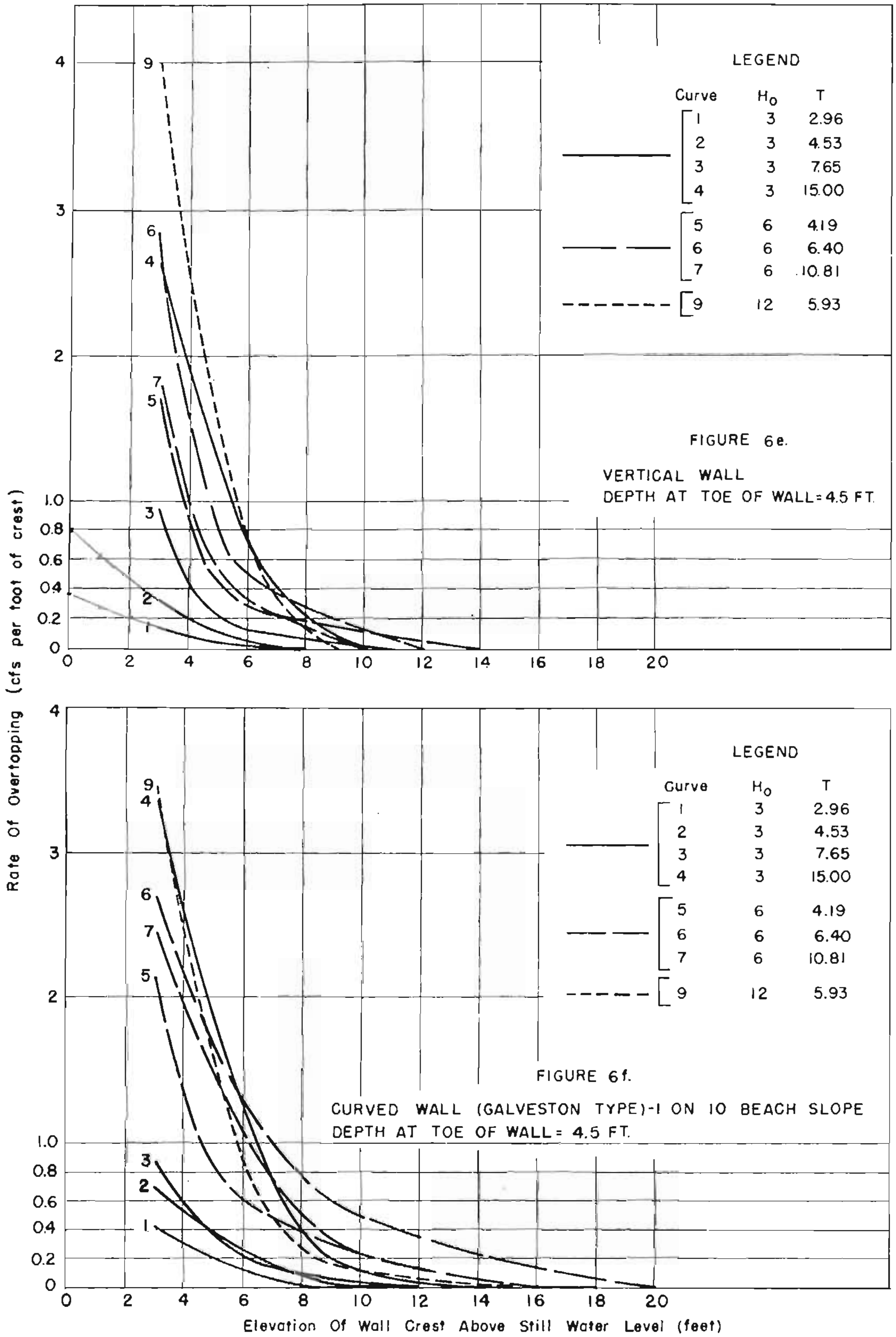
FIGURE 5 f,g · ELEMENTS OF TEST SECTIONS



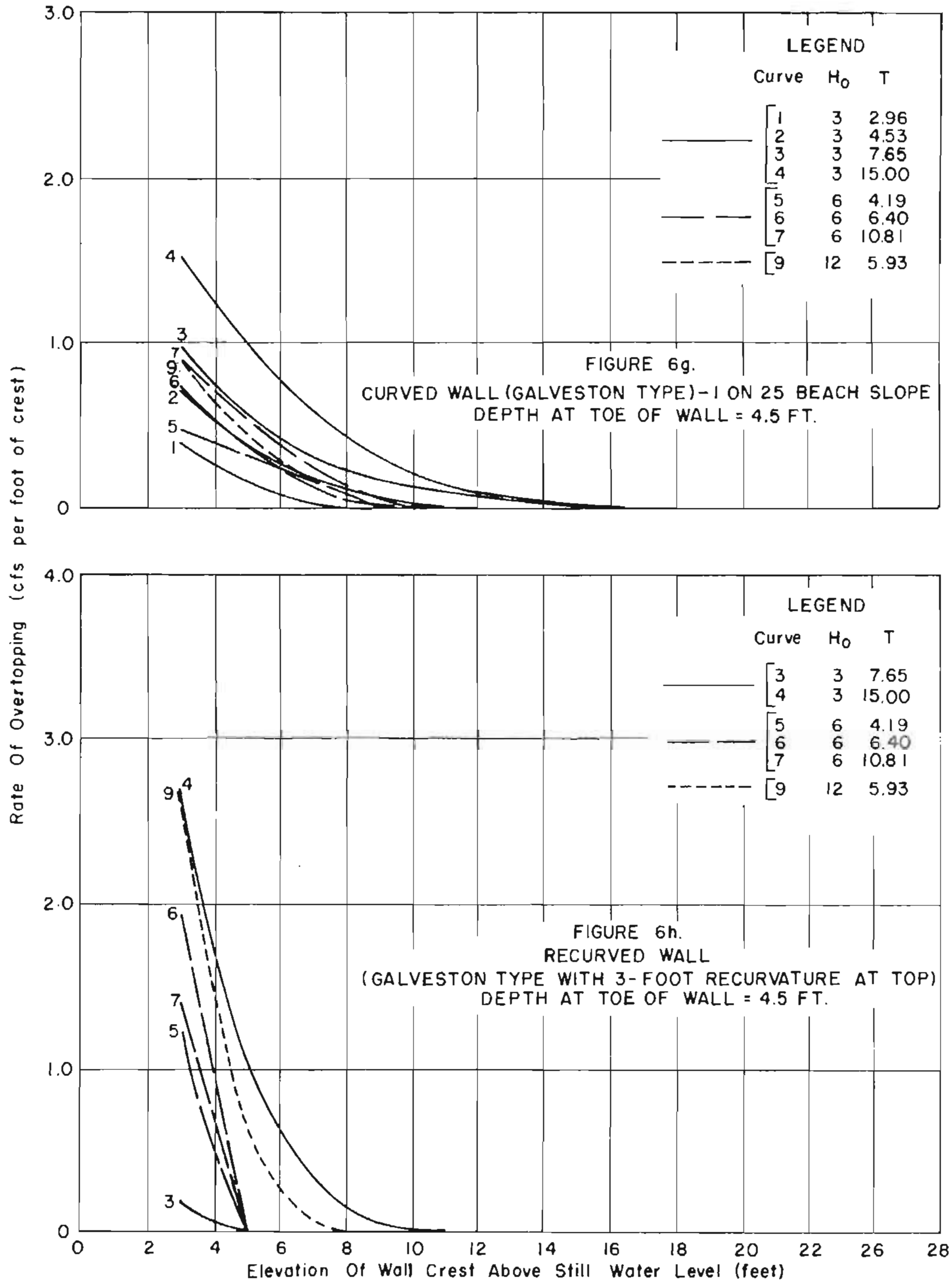
FIGURES 6a, 6b. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST



FIGURES 6c, 6d. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST



FIGURES 6e, 6f. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST



FIGURES 6g, 6h · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

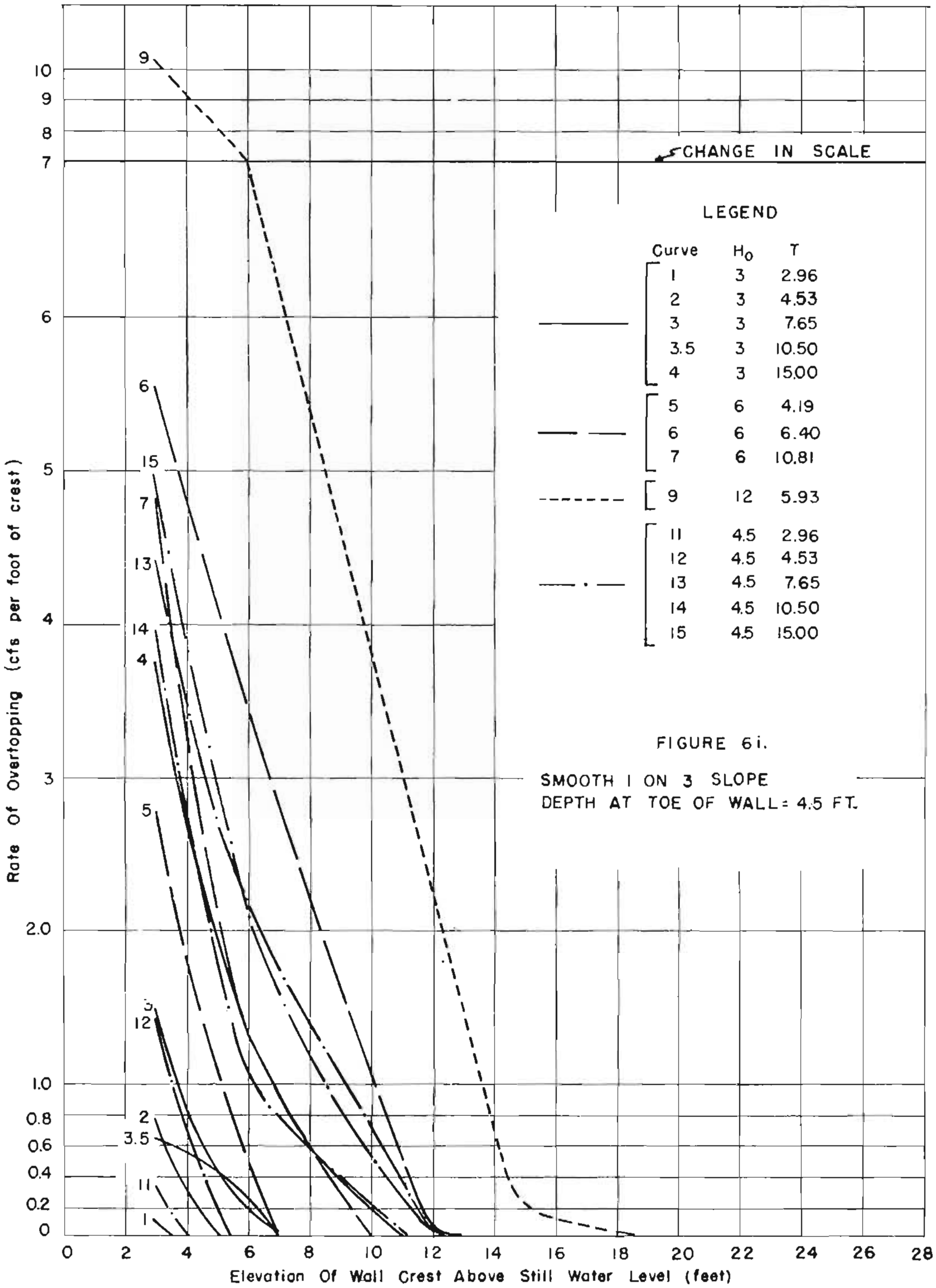


FIGURE 6i. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

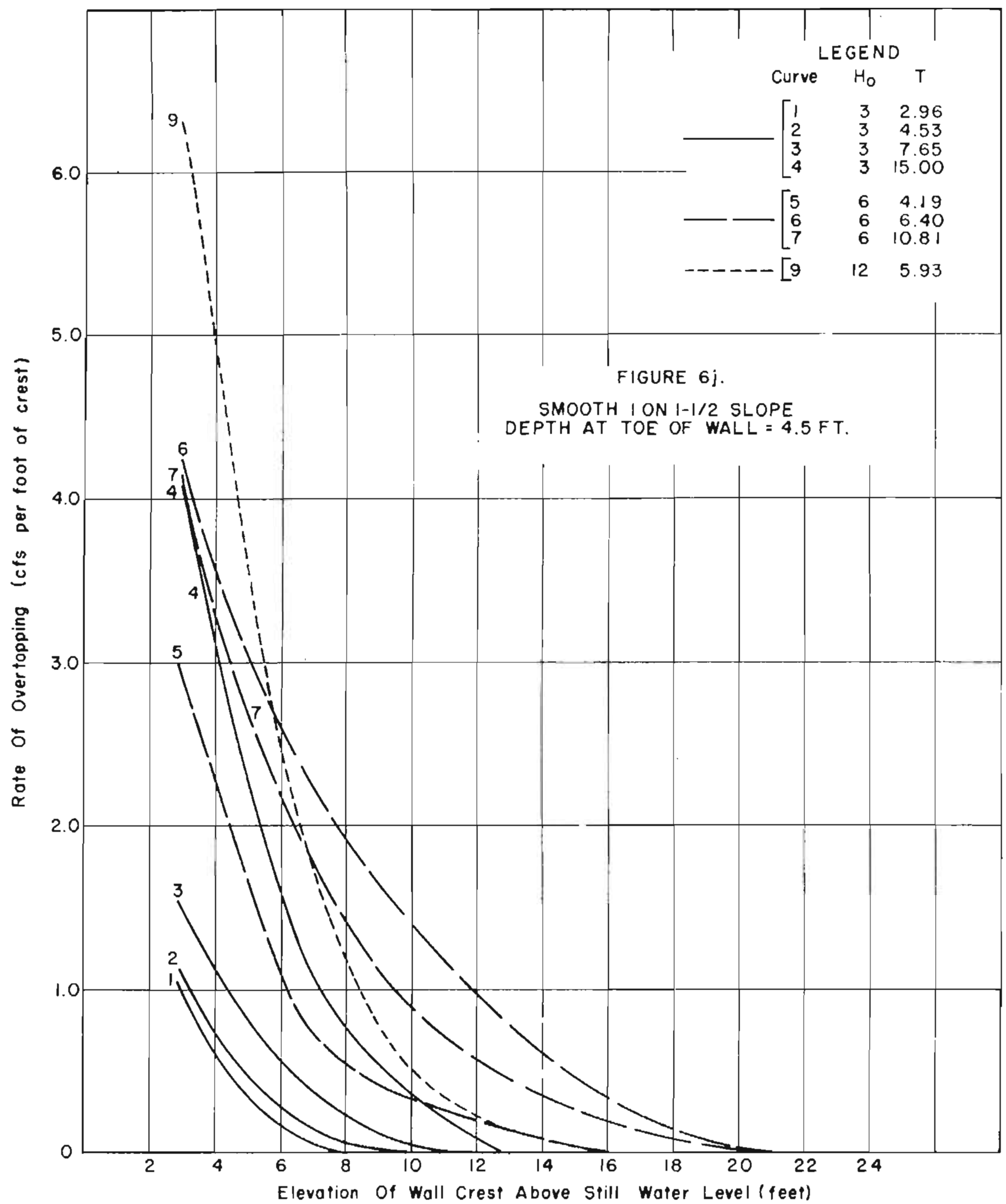


FIGURE 6j · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

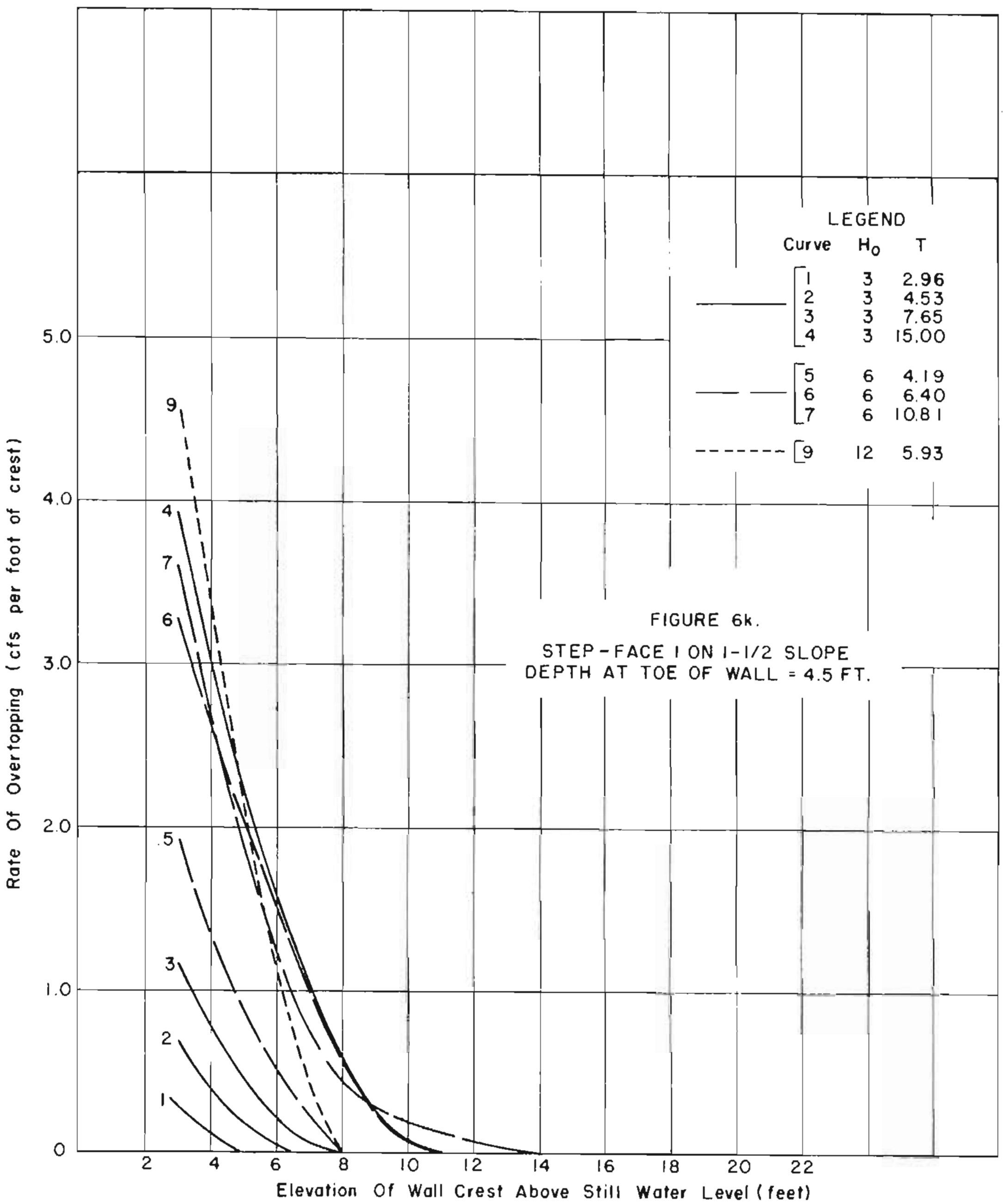


FIGURE 6k · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

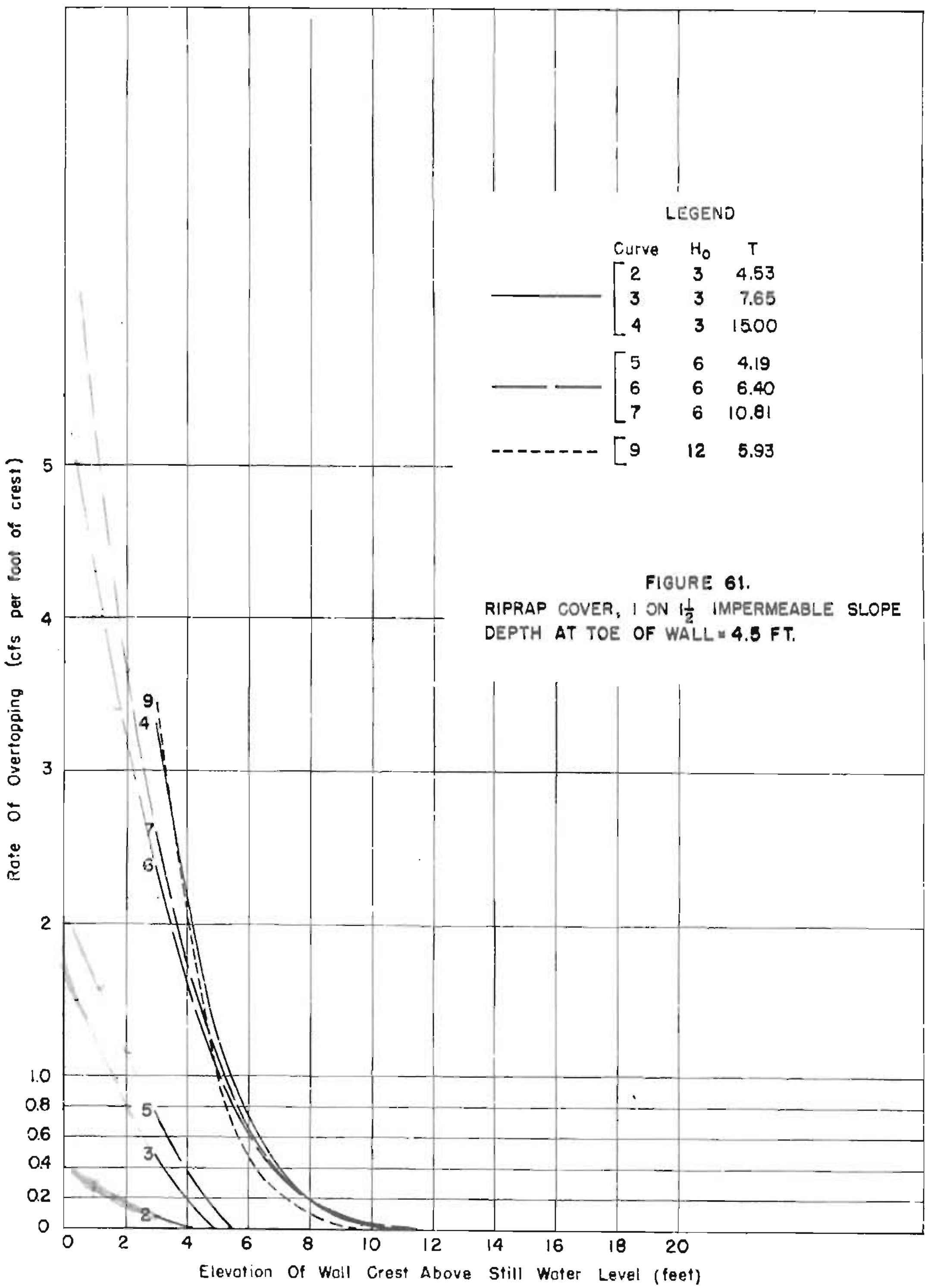


FIGURE 61. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

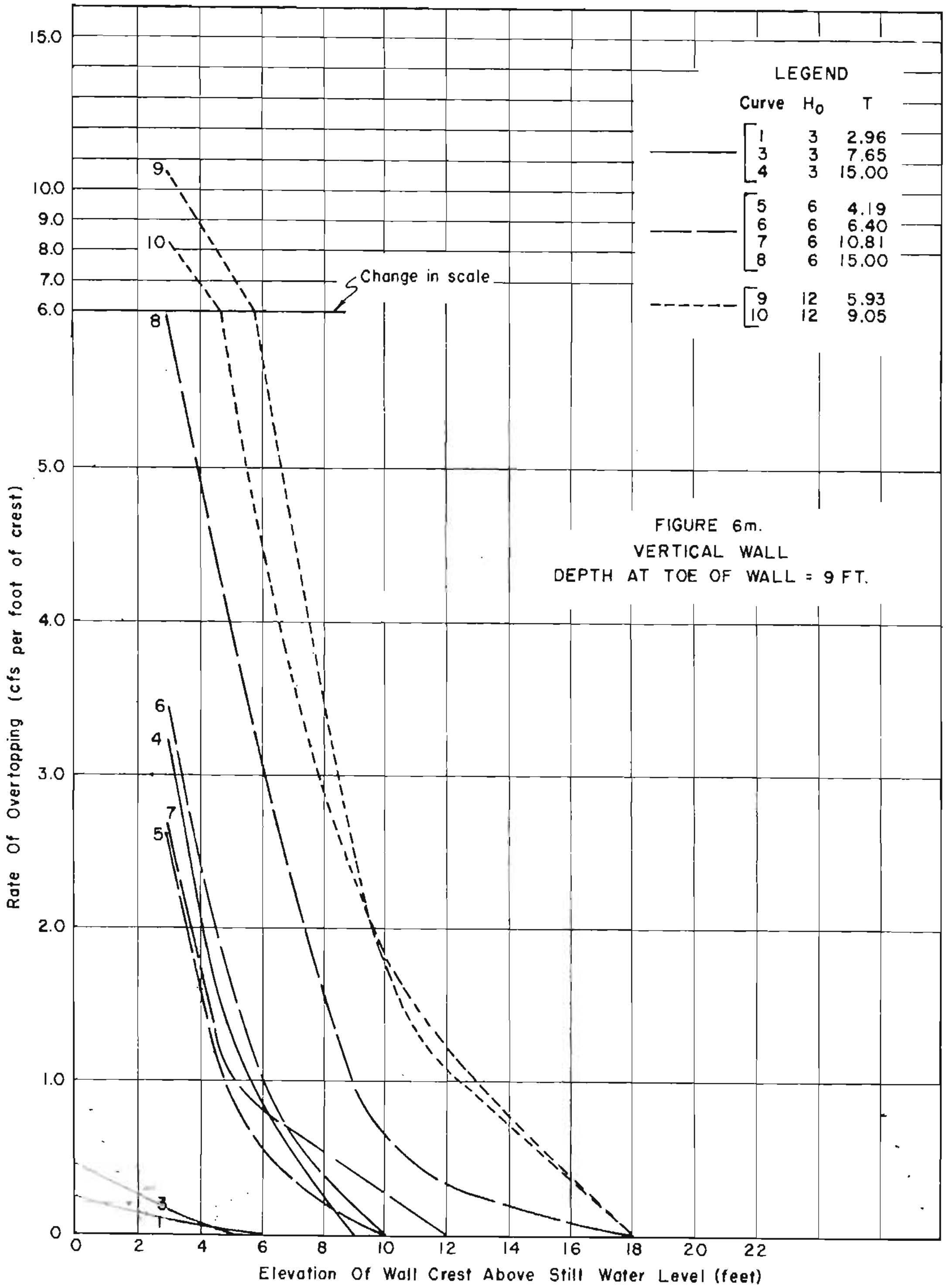


FIGURE 6m · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

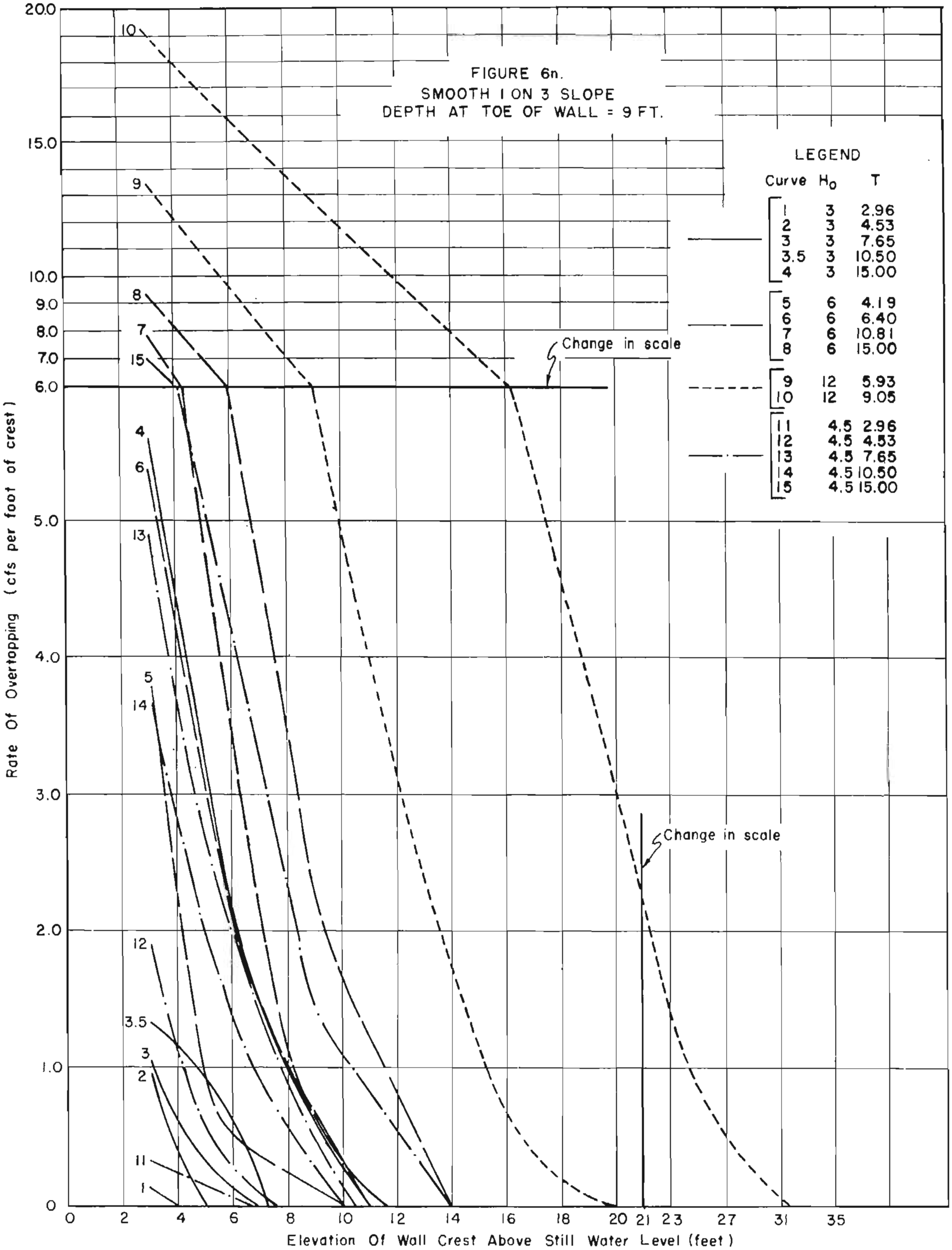


FIGURE 6n · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

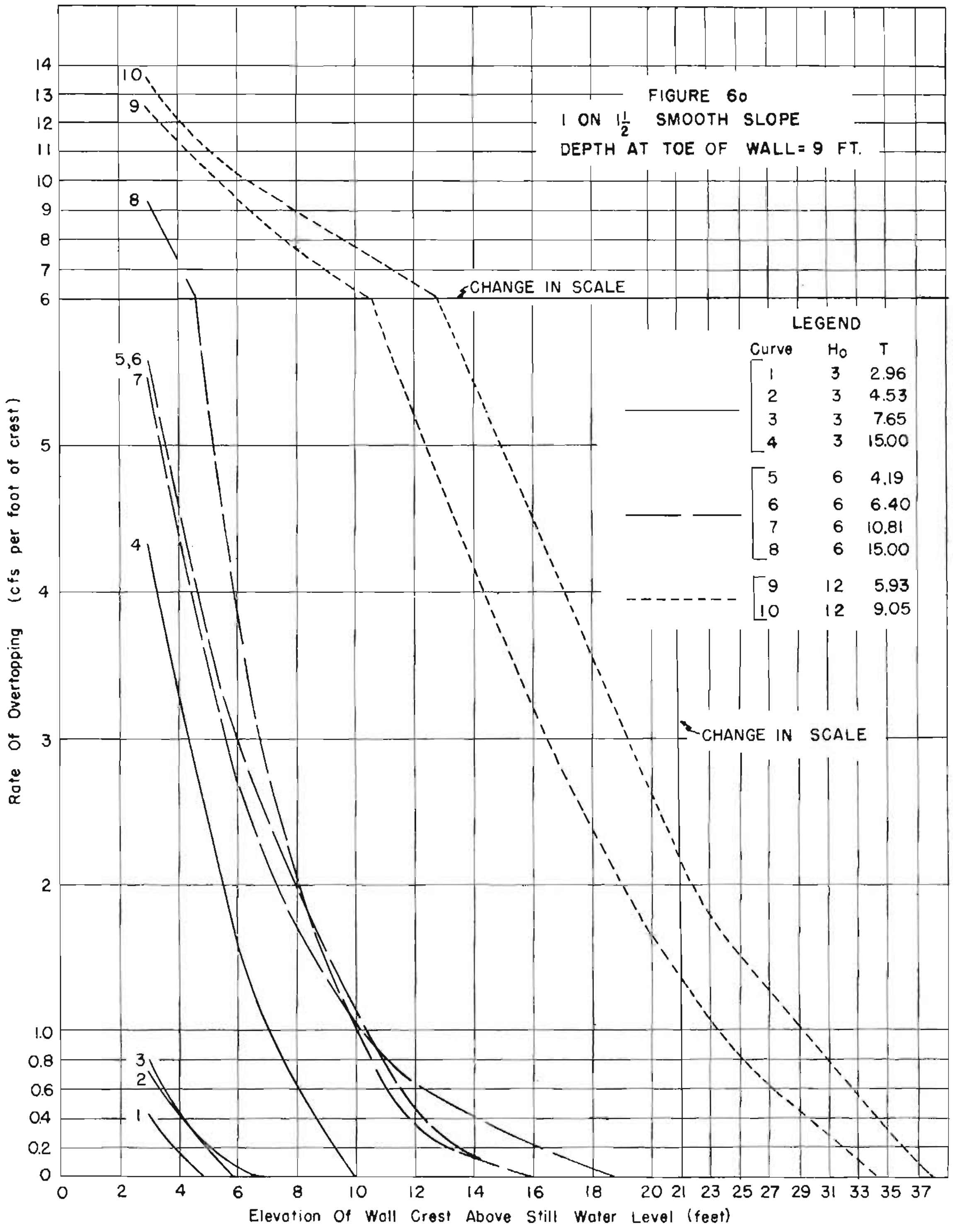


FIGURE 6a. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

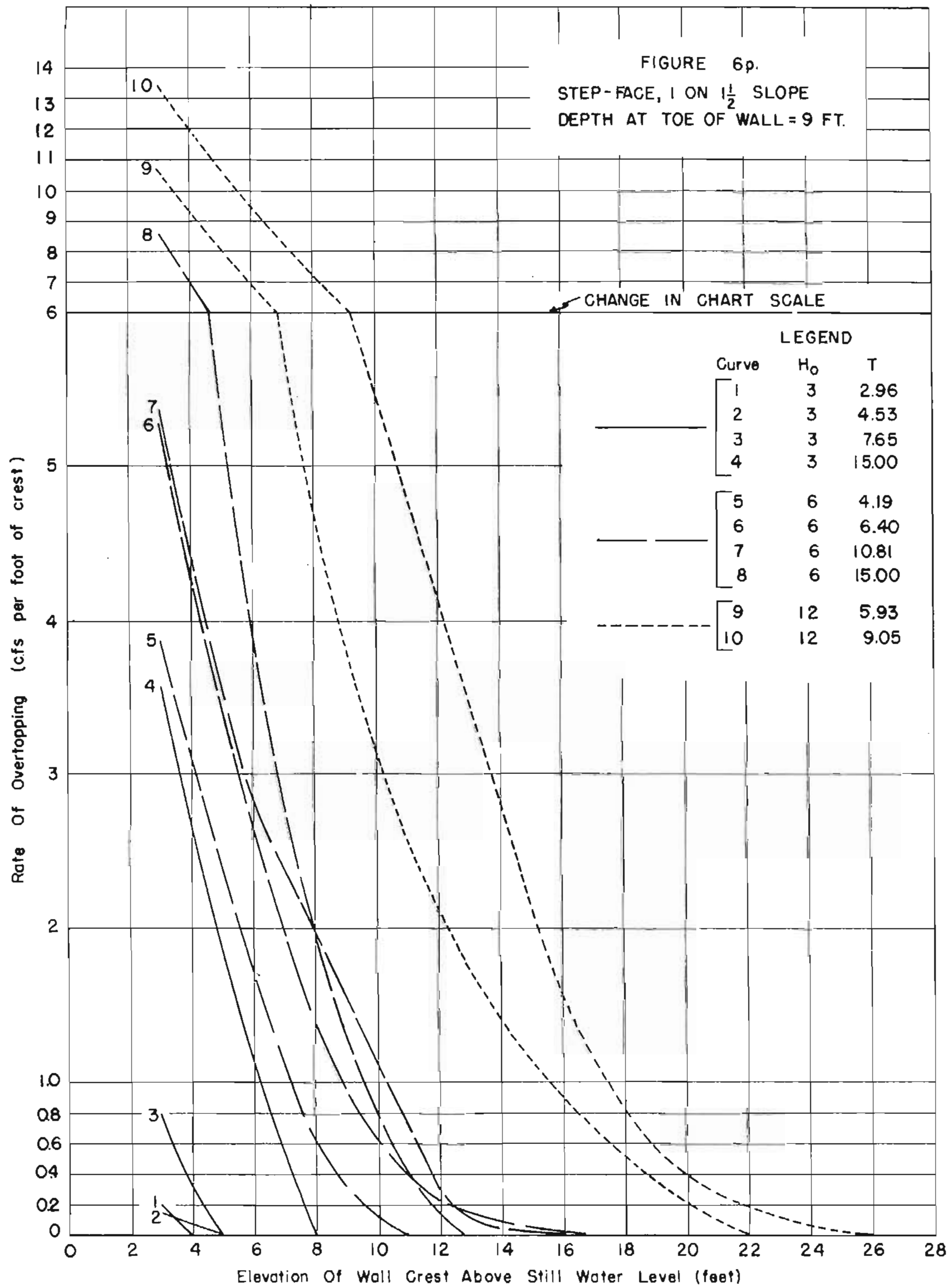


FIGURE 6p. RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

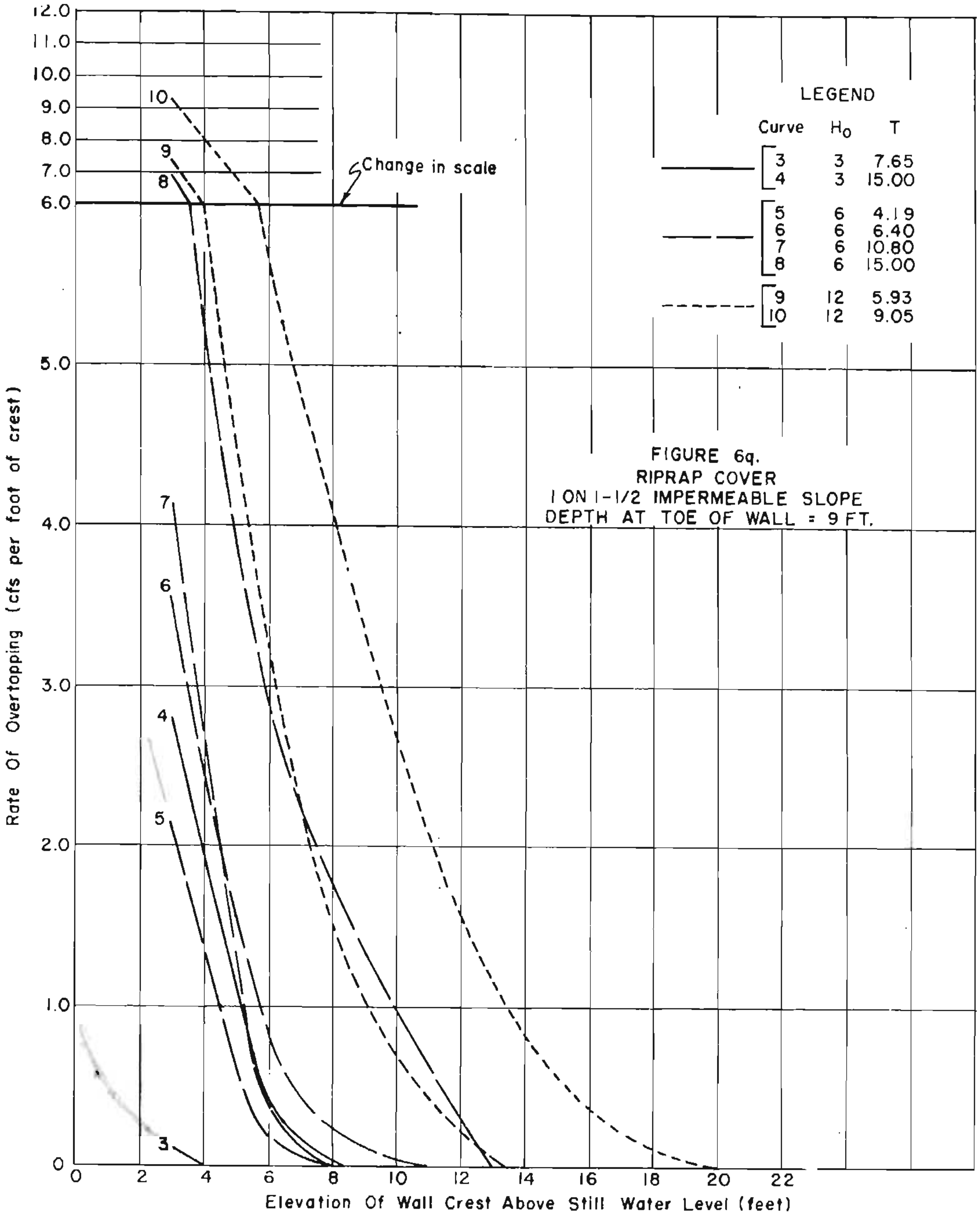
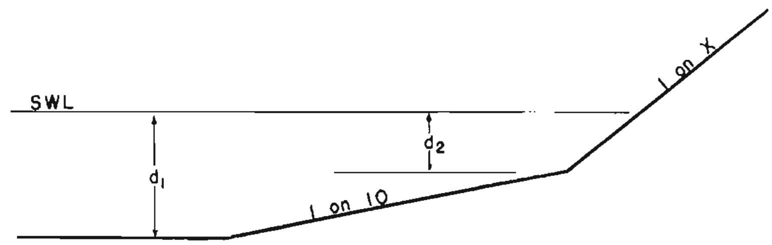


FIGURE 6q · RELATION OF RATE OF OVERTOPPING TO ELEVATION OF WALL CREST

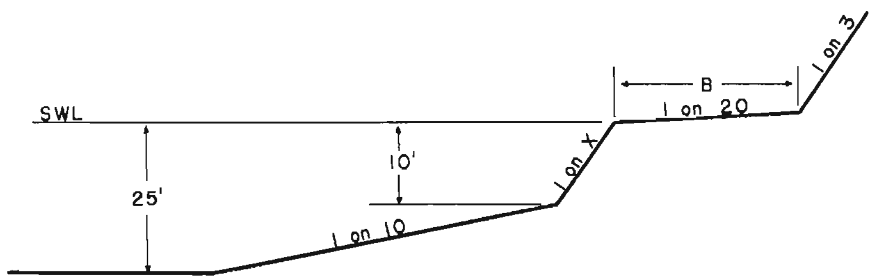


d_1 = 10, 17.5 and 25 feet

d_2 = 5 and 10 feet

1 on X = 1 on 2, 1 on 3, 1 on 4, 1 on 6, and 1 on 10

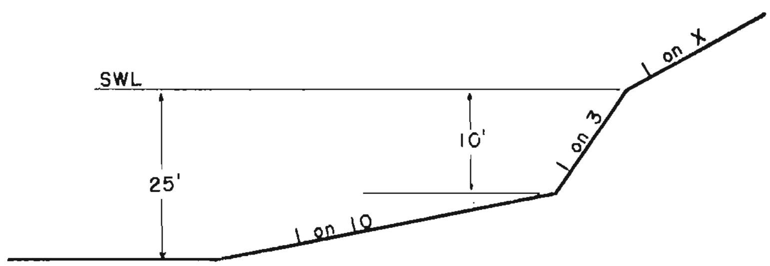
a. Smooth Slope

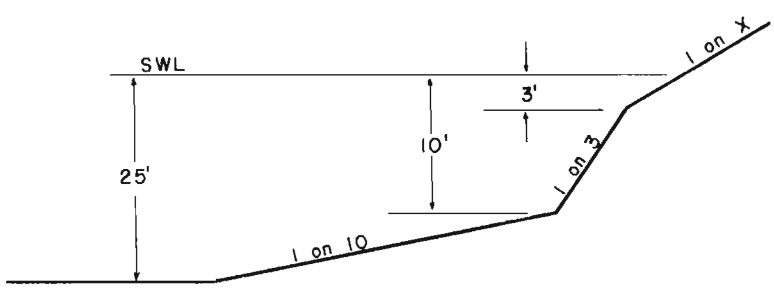


1 on X = 1 on 3 and 1 on 6

B = 30, 50 and 70 feet

b. Smooth Slope With Berm

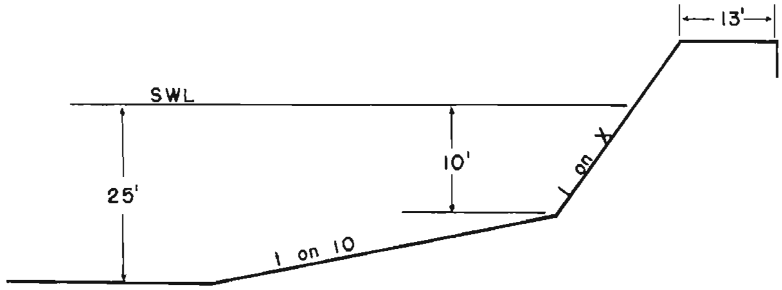




1 on X = 1 on 6 and 1 on 10

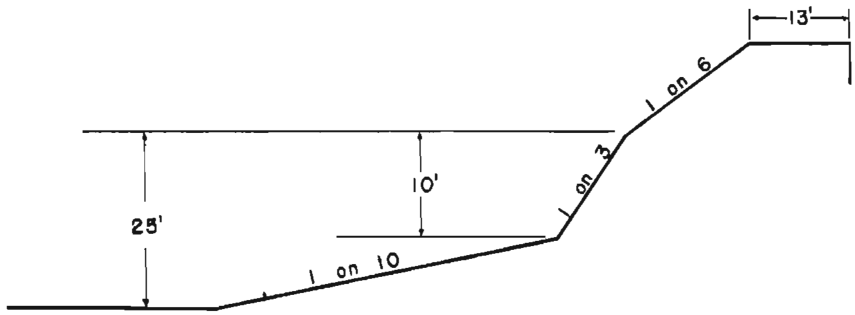
c. Composite Slope

FIGURE 7. ELEMENTS OF TEST SECTIONS - JACKSONVILLE DISTRICT RUN-UP TESTS



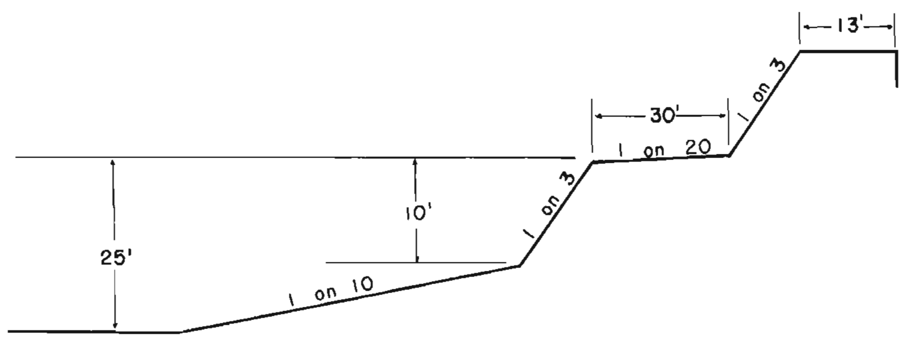
1 on X = 1 on 3 and 1 on 6
Crest Elevation at $1/4$ h, $1/2$ h, $3/4$ h, and h Where
h = Vertical Height Of Run - Up

a. Smooth Slope



Crest Elevation at $1/4$ h, $1/2$ h, $3/4$ h, and h, Where h = Vertical
Height Of Run-Up

b. Composite Slope



Crest Elevation at 1.5 Feet, $1/4$ h, $1/2$ h, $3/4$ h, and h, Where h = Vertical
Height Of Run-Up

c. Smooth 1 On 3 Slope With Berm

FIGURE 8. ELEMENTS OF TEST SECTIONS - JACKSONVILLE
DISTRICT OVERTOPPING TESTS

TABLE 1

Run-up Values (feet above still water level): BEB-WES Data (Considered as 1 to 17 Model Scale)

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall-Galveston Type - Beach Slope 1:25	Recurved Wall-Galveston Type with 3-foot Recurvature Added	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 0 feet									
3.0	2.96	2					3	1	1
3.0	4.53	3					4	2	2
3.0	7.65	4.5					5	4	4
3.0	15.00	12					14	10	8
6.0	4.19	4(1)					5	2	2
6.0	6.40	6					8	5	5
6.0	10.81	11(2)					13	11	8.5
Depth at Toe of Structure = 4.5 feet									
3.0	2.96	12(2)	12	14(4)	2(5)	3.5	10	5	2.5
3.0	4.53	8	11	16(4)	2	5	10	7	4.5
3.0	7.65	11	12	18	5	7	12	8	5
3.0	10.50					7			
3.0	15.00	10	15	18	11	11	13	11	11
4.5	2.96					4			
4.5	4.53					5.5			
4.5	7.65					13			
4.5	10.50					11			
4.5	15.00					12.5			
6.0	4.19	14	18	10(2)	5	7	16	8	5.5
6.0	6.40	12	20	13(4)	5	13	22	11	10.5
6.0	10.81	10	18	14(4)	5	10	20	14	11.5
12.0	5.93	9	18	14(4)	8	19	16	8	10
Depth at Toe of Structure = 9.0 feet									
3.0	2.96	6				4	7	4	2
3.0	4.53	3.5(1)				5	5	5	2.5
3.0	7.65	5				7	6	5	4
3.0	10.50					6.5			
3.0	15.00	9				11	10	8	8
4.5	2.96					6.5			
4.5	4.53					7.5			
4.5	7.65					10.5			
4.5	10.50					10			
4.5	15.00					13			
6.0	4.19	10				10	16	11	8
6.0	6.40	10				11	16	16	11
6.0	10.81	11				11.5	19	16	8.5
6.0	15.00	18				14	16	13	13
12.0	5.93	16				20	34	22	13.5
12.0	9.05	20(3)				31.5	37	26	20

(1) No overtopping was observed for a wall crest height of 3 feet, despite higher run-up values shown.
(2) No overtopping was observed for a wall crest height of 9 feet, despite higher run-up values shown.
(3) No overtopping was observed for a wall crest height of 18 feet, despite higher run-up values shown.
(4) No overtopping was observed for a wall crest height of 12 feet, despite higher run-up values shown.
(5) Run-up values for recurved wall are heights to which wall must be built to prevent any overtopping, not actual heights of rise of water.

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TABLE 2

Rate of Overtopping (cfs per foot of crest) BEB-WES Data (Considered as 1 to 17 Model Scale)

Crest Elevation 3 Feet Above Still Water Level

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall-Galveston Type - Beach Slope 1:25	Recurved Wall-Galveston Type with 3-foot Recurvature Added	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 0 feet									
3.0	2.96	0.00					0.00	0.00	0.00
3.0	4.53	0.00					0.02	0.00	0.00
3.0	7.65	0.04					0.20	0.06	0.03
3.0	15.00	0.99					2.50	2.35	2.51
6.0	4.29	0.00					0.11	0.00	0.00
6.0	6.40	0.32					0.83	0.45	0.36
6.0	10.81	1.76					3.29	2.60	2.71
Depth at Toe of Structure = 4.5 feet									
3.0	2.96	0.14	0.42	0.39	0.00	0.09	1.06	0.28	0.00
3.0	4.53	0.34	0.69	0.70	0.00	0.75	1.13	0.67	0.09
3.0	7.65	0.95	0.88	0.95	0.19	1.47	1.55	1.16	0.48
3.0	10.50					0.63			
3.0	15.00	2.65	3.37	1.53	2.67	3.74	4.15	3.91	3.31
4.5	2.96					0.31			
4.5	4.53					1.45			
4.5	7.65					4.40			
4.5	10.50					3.94			
4.5	15.00					4.94			
6.0	4.19	1.72	2.14	0.48	1.21	2.77	2.98	1.92	0.76
6.0	6.40	2.84	2.69	0.71	1.94	5.54	4.23	3.28	2.38
6.0	10.81	1.79	2.45	0.90	1.39	4.98	4.08	3.61	2.59
12.0	5.93	3.99	3.45	0.92	2.68	10.25	6.37	4.51	3.41
Depth at Toe of Structure = 9.0 feet									
3.0	2.96	0.07				0.12	0.73	0.19	0.00
3.0	4.53	0.00				0.94	0.44	0.15	0.00
3.0	7.65	0.14				1.03	0.80	0.80	0.11
3.0	10.50					1.18			
3.0	15.00	3.24				5.62	4.33	3.57	2.80
4.5	2.96					0.31			
4.5	4.53					1.90			
4.5	7.65					4.89			
4.5	10.50					3.68			
4.5	15.00					7.03			
6.0	4.19	2.52				3.79	5.45	3.87	2.14
6.0	6.40	3.43				5.38	5.57	5.24	3.55
6.0	10.81	2.70				7.83	5.46	5.34	4.12
6.0	15.00	6.01				9.35	9.26	8.51	6.87
12.0	5.93	10.58				13.49	12.60	10.70	7.36
12.0	9.05	8.30				19.29	13.55	13.34	9.21

TABLE 2 (Continued)

Rate of Overtopping (cfs per foot of crest) BEB-WES Data (Considered as 1 to 17 Model Scale)

Crest Elevation 6 Feet Above Still Water Level

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall-Galveston Type - Beach Slope 1:25	Recurved Wall-Galveston Type with 3-foot Recurvature Added	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 0 feet									
3.0	2.96	0.00							
3.0	4.53	0.00							
3.0	7.65	0.00					0.00	0.00	0.00
3.0	15.00	0.28					1.06	0.76	0.44
6.0	4.19	0.00					0.00		
6.0	6.40	0.00					0.09	0.00	0.00
6.0	10.81	0.29					1.70	1.07	0.55
Depth at Toe of Structure = 4.5 feet									
3.0	2.96	0.02	0.13	0.08		0.00	0.21	0.00	
3.0	4.53	0.04	0.27	0.27		0.00	0.31	0.03	0.00
3.0	7.65	0.13	0.24	0.41	0.00	0.15	0.60	0.19	0.00
3.0	10.50					0.28			
3.0	15.00	0.75	1.25	0.77	0.61	1.35	1.68	1.57	0.71
4.5	2.96					0.00			
4.5	4.53					0.00			
4.5	7.65					2.06			
4.5	10.50					0.94			
4.5	15.00					2.20			
6.0	4.19	0.29	0.62	0.09	0.00	0.46	1.17	0.51	0.00
6.0	6.40	0.51	1.26	0.24	0.00	3.45	2.57	1.47	0.61
6.0	10.81	0.34	1.10	0.39	0.00	1.38	2.21	1.20	0.64
12.0	5.93	0.71	0.87	0.30	0.26	7.07	2.50	1.03	0.47
Depth at Toe of Structure = 9.0 feet									
3.0	2.96	0.00				0.00	0.08	0.00	
3.0	4.53	0.00				0.00	0.00	0.00	
3.0	7.65	0.00				0.11	0.00	0.00	0.00
3.0	10.50					0.62			
3.0	15.00	0.86				2.18	1.59	1.14	0.42
4.5	2.96					0.08			
4.5	4.53					0.26			
4.5	7.65					1.99			
4.5	10.50					1.35			
4.5	15.00					4.15			
6.0	4.19	0.55				0.48	2.98	1.69	0.18
6.0	6.40	1.01				3.03	2.99	2.63	0.89
6.0	10.81	0.85				3.37	2.71	2.78	0.41
6.0	15.00	3.12				5.82	3.82	3.89	2.89
12.0	5.93	5.85				9.54	9.36	6.87	3.23
12.0	9.05	4.52				16.48	10.28	9.41	5.65

TABLE 2 (Continued)

Rate of Overtopping (cfs per foot of crest) [illegible]-WES Data (Considered as 1 to 17 Model Scale)

Crest Elevation 9 Feet Above Still Water Level

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall-Galveston Type - Beach Slope 1:25	Recurved Wall-Galveston Type with 3-foot Recurvature Added	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 0 feet									
3.0	2.96								
3.0	4.53								
3.0	7.65								
3.0	15.00	0.02					0.26	0.05	0.00
6.0	4.19								
6.0	6.40						0.00		
6.0	10.81	0.00					0.45	9.21	0.00
Depth at Toe of Structure = 4.5 feet									
3.0	2.96	0.00	0.01	0.01			0.01		
3.0	4.53		0.03	0.10			0.02		
3.0	7.65	0.05	0.07	0.18		0.00	0.14	0.00	
3.0	10.50					0.00			
3.0	15.00	0.12	0.19	0.31	0.05	0.39	0.56	0.23	0.07
4.5	2.96								
4.5	4.53								
4.5	7.65					0.85			
4.5	10.50					0.48			
4.5	15.00					1.03			
6.0	4.19	0.13	0.40	0.00		0.00	0.42	0.00	
6.0	6.40	0.21	0.61	0.04		1.60	1.66	0.22	0.10
6.0	10.81	0.09	0.33	0.06		0.35	1.10	0.28	0.09
12.0	5.93		0.38	0.07	0.00	4.63	0.78	0.00	0.05
Depth at Toe of Structure = 9.0 feet									
3.0	2.96								
3.0	4.53								
3.0	7.65					0.00			
3.0	10.50					0.00			
3.0	15.00					0.62	0.31	0.00	0.00
4.5	2.96					0.00			
4.5	4.53					0.00			
4.5	7.65					0.50			
4.5	10.50					0.30			
4.5	15.00					1.38			
6.0	4.19	0.15				0.14	1.58	0.32	0.00
6.0	6.40	0.21				0.68	1.55	0.94	0.10
6.0	10.81	0.57				0.66	1.4[illegible]	1.36	0.00
6.0	15.00	1.02				2.24	1.46	1.28	1.37
12.0	5.93	2.52				6.04	6.99	2.63	1.05
12.0	9.05	2.39				12.16	8.48	6.12	3.42

TABLE 2 (Continued

Rate of Overtopping (cfs per foot of crest) BEB-WES Data (Considered as 1 to 17 Model Scale)

Crest Elevation 12 Feet Above Still Water Level

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall - Galveston Type - Beach Slope 1:25	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 0 feet								
3.0	2.96							
3.0	4.53							
3.0	7.65							
3.0	15.00					0.03	0.00	
6.0	4.19							
6.0	6.40							
6.0	10.81					0.11	0.00	
Depth at Toe of Structure = 4.5 feet								
3.0	2.96		0.00	0.00		0.00		
3.0	4.53		0.00	0.00		0.00		
3.0	7.65		0.00	0.06		0.00		
3.0	10.50							
3.0	15.00		0.05	0.08	0.00	0.09	0.00	
4.5	2.96							
4.5	4.53							
4.5	7.65				0.02			
4.5	10.50				0.00			
4.5	15.00				0.02			
6.0	4.19	0.06	0.11			0.20		
6.0	6.40		0.36	0.00	0.06	0.98	0.00	
6.0	10.81		0.17	0.00	0.00	0.63	0.09	
12.0	5.93		0.07	0.00	2.27	0.24		
Depth at Toe of Structure = 9.0 feet								
3.0	2.96							
3.0	4.53							
3.0	7.65							
3.0	10.50							
3.0	15.00				0.00	0.00		
4.5	2.96							
4.5	4.53							
4.5	7.65				0.00			
4.5	10.50				0.00			
4.5	15.00				0.62			
6.0	4.19				0.00	0.46	0.00	
6.0	6.40				0.00	0.45	0.24	0.00
6.0	10.81				0.00	0.64	0.28	
6.0	15.00	0.34			0.79	0.36	0.13	0.31
12.0	5.93	1.22			3.23	4.72	2.37	0.21
12.0	9.05	1.09			9.65	6.68	4.19	1.57

TABLE 2 (Continued)

Rate of Overtopping (cfs per foot of crest) BEB-WES Data (Considered as 1 to 17 Model Scale)

Crest Elevations Greater Than 12 Feet Above Still Water Level

Beach Slope Fronting Structure is 1 on 10 Unless Otherwise Indicated

Deep Water Wave Height (feet)	Wave Period (sec)	Crest Elevations (feet)	Vertical Wall	Curved Wall-Galveston Type - Beach Slope 1:10	Curved Wall-Galveston Type - Beach Slope 1:25	1 on 3 Slope Smooth Face	1 on 1 1/2 Slope Smooth Face	1 on 1 1/2 Slope Stepped-Face	1 on 1 1/2 Slope Riprap Cover
Depth at Toe of Structure = 4.5 feet									
3.0	2.96								
3.0	4.53								
3.0	7.65	15			0.03				
		18			0.00				
3.0	10.50								
3.0	15.00	15		0.00	0.05		0.00	0.00	
		18			0.00				
4.5	2.96								
4.5	4.53								
4.5	7.65	15				0.00			
4.5	10.50								
4.5	15.00	15		•		0.00			
6.0	4.19	15		0.06			0.06		
		18		0.00			0.00		
6.0	6.40	15		0.22		0.00	0.46		
		18		0.05			0.11		
		21					0.02		
6.0	10.81	15		0.06			0.26	0.00	
		18		0.00			0.09		
		21					0.00		
12.0	10.90	15		0.03		0.15	0.04		
		18		0.00		0.14	0.00		
		21				0.00			
Depth at Toe of Structure = 9.0 feet									
3.0	2.96								
3.0	4.53								
3.0	7.65								
3.0	10.50								
3.0	15.00								
4.5	2.96								
4.5	4.53								
4.5	7.65								
4.5	10.50								
4.5	15.00	15				0.00			
6.0	4.19	15					0.09		
		18					0.00		
6.0	6.40	15					0.09	0.11	
		18					0.00	0.00	
6.0	10.81	15					0.33	0.02	
		18					0.09	0.00	
		21					0.00		
6.0	15.00	15	0.14			0.00	0.11	0.00	0.00
		18					0.00		
12.0	5.93	15	0.67			1.15	3.72	1.24	0.00
		18				0.19	2.38	0.43	
		21				0.00	1.39	0.16	
		24					0.94	0.00	
		27					0.64		
		30					0.35		
		33					0.12		
		36					0.00		
12.0	9.05	15	0.58			7.01	4.98	2.05	0.58
		18				4.82	3.76	0.82	0.10
		21				2.20	2.18	0.25	
		24				1.05	1.64	0.10	
		27				0.54	1.28		
		30				0.10	0.95		
		33					0.37		
		36					0.28		

TABLE 3

Run-up Values (feet above still water level)

Jacksonville District--WES Data (Considered as 1 to 30 Model Scale)

Beach Slope Fronting Structure is 1 on 10

Wave Height at Beach Toe (feet)	Wave Period (sec.)	1 on 2 Smooth Slope		1 on 3 Smooth Slope		1 on 4 Smooth Slope		1 on 6 Smooth Slope		1 on 10 Smooth Slope	
	Depth at Toe of Structure =	10 feet	5 feet	10 feet	5 feet	10 feet	5 feet	10 feet	5 feet	10 feet	5 feet
Depth at Toe of Beach (1 on 10) Slope = 20 feet											
4.0	4.5	9.9	9.7	6.3	6.7	5.2	4.8	3.2	3.0	1.9	1.9
4.0	5.5	9.3	13.3	9.1	9.3	6.5̄	6.6	4.3	3.9	2.3	2.3
Depth at Toe of Beach (1 on 10) Slope = 17.5 feet											
4.0	4.5	8.7	11.7	6.5	8.2	4.9	5.9	3.7	3.6	2.2	2.2
4.0	5.5	9.5	11.9	8.7	9.8	6.2	7.1	4.1	4.0	2.4	2.4
6.0	4.5	12.4	9.0	10.6	6.5	7.1	4.7	3.7	3.5	2.2	2.2
6.0	5.5	16.7	11.4	14.9	8.3	9.3	6.5	5.4	4.2	2.8	2.8
8.0	5.0	14.8	11.3	11.5	7.6	7.9	4.8	4.5	4.1	2.8	2.8
8.0	6.0	21.6	10.7	15.2	9.1	10.1	7.9	6.4	5.3	3.6	3.6
Depth at Toe of Beach (1 on 10) Slope = 25 feet											
4.0	4.5	8.3	11.0	6.3	8.0	4.8	5.5	3.5	3.5	1.6	1.6
4.0	5.5	8.5	11.6	7.9	9.6	6.2	7.0	3.9	4.6	2.1	2.1
6.0	4.5	13.4	11.3	9.1	7.4	7.5	5.2	4.2	3.4	2.1	2.1
6.0	5.5	16.2	13.7	12.0	9.3	8.9	7.6	6.0	4.7	2.8	2.8
8.0	5.0	20.1	8.7	11.9	7.9	·8.5	6.0	4.6	4.1	2.7	2.7
8.0	6.0	22.8	12.6	14.3	9.6	10.1	7.8	6.8	5.4	3.5	3.5
10.0	5.5	18.8	10.6	11.7	9.0	8.8	6.8	5.1	4.8	3.1	3.1
10.0	6.5	23.2	12.1	14.6	10.4	11.1	8.6	7.0	6.0	4.1	4.1
12.0	6.0	17.7	14.0	12.2	10.5	9.2	8.1	6.0	5.9	4.1	4.1
12.0	7.0	20.5	12.8	15.2	12.5	12.0	10.6	7.3	7.4	5.4	5.4

Wave Height at Beach Toe (25-foot depth) (feet)	Wave Period (sec)	1 on 3 Smooth Slope with 1 on 20 Sloped Berm at Still Water Level; Berm Widths of			1 on 6 Smooth Slope with 1 on 20 Sloped Berm at Still Water Level; Berm Widths of			Composite Slope 1 on 3 slope below still water		Composite Slope 1 on 3 slope below -3	
		30 ft.	50 ft.	70 ft.	30 ft.	50 ft.	70 ft.	1 on 6 above water	1 on 10 above water	1 on 6 above -3	1 on 10 above -3
Depth at Toe of Structure = 10 feet											
6.0	4.5	4.7	4.3	4.1	3.9	3.4	2.9	6.0	4.8	4.4	3.4
6.0	5.5	6.6	5.3	5.0	5.7	4.3	3.6	7.4	5.6	6.0	4.1
8.0	5.0	6.3	5.8	5.4	5.2	4.3	3.6	8.3	6.2	6.0	4.5
8.0	6.0	8.1	6.9	6.0	7.1	5.6	4.?	9.3	5.9	7.4	5.2
10.0	5.5	8.9	7.5	6.2	5.4	4.7	3.6	9.2	6.7	7.4	5.3
10.0	6.5	12.1	9.2	8.1	8.2	6.3	5.2	10.5	7.7	8.6	6.2
12.0	6.0	11.0	8.4	7.1	7.4	5.7	4.6	9.9	7.5	8.6	6.3
12.0	7.0	15.6	10.6	9.0	9.8	7.5	6.1	12.1	8.9	10.3	7.3

TABLE 4

Rate of Overtopping (cfs per foot of crest)

Jacksonville District—WES Data (Considered as 1 to 30 Model Scale)

Beach Slope Fronting Structures is 1 on 10

Wave Height at Beach Toe (25-foot depth) (feet)	Wave Period (sec)	1 on 3 Smooth Slope					1 on 6 Smooth Slope				
		Wave Run-up, h (feet)	Crest Elevations of 1/4 h	1/2 h	3/4 h	h	Wave Run-up, h (feet)	Crest Elevations of 1/4 h	1/2 h	3/4 h	h
Depth at Toe of Structure = 10 feet											
4.0	4.5	6.3	2.60	1.60	0.20	0.00	3.5	1.80	0.80	0.20	0.00
4.0	5.5	7.9	2.62	1.15	0.16	0.00	3.9	2.13	0.98	0.16	0.00
6.0	4.5	9.1	4.20	1.80	0.40	0.00	4.2	2.20	1.40	0.40	0.00
6.0	5.5	12.0	4.58	1.80	0.33	0.00	6.0	4.25	1.64	0.16	0.00
8.0	5.0	11.9	5.94	2.52	1.08	0.18	4.6	4.68	2.16	0.72	0.00
8.0	6.0	14.3	6.60	3.45	1.35	0.45	6.8	5.85	2.25	0.30	0.00
10.0	5.5	11.7	7.21	4.42	1.31	0.65	5.1	6.71	4.09	1.47	0.49
10.0	6.5	14.6	8.88	5.00	1.53	0.14	7.0	7.20	3.05	0.83	0.28
12.0	6.0	12.2	11.10	5.40	1.95	0.90	6.0	8.10	3.90	1.50	0.60
12.0	7.0	15.2	10.80	6.43	2.32	0.51	7.3	10.69	5.27	1.54	0.51

Wave Height at Beach Toe (25-foot depth) (feet)	Wave Period (sec)	Composite Slope - 1 on 3 below still water level, 1 on 6 above water					1 on 3 Slope with 1 on 20 Berm 30 feet wide at swl					
		Wave Run-up, h (feet)	Crest Elevations of 1/4 h	1/2 h	3/4 h	h	Wave Run-up, h (feet)	Crest Elevations of 1.5 feet	1/4 h	1/2 h	3/4 h	h
Depth at Toe of Structure = 10 feet												
4.0	4.5	3.4	No Test	2.60	1.40	0.40	2.3	0.40	No Test	No Test	0.20	0.00
4.0	5.5	4.4	3.61	1.97	0.66	0.00	3.3	1.15	No Test	0.98	0.16	0.00
6.0	4.5	6.0	4.60	3.00	0.60	0.00	4.7	4.20	No Test	1.80	0.40	0.00
6.0	5.5	7.4	5.07	1.97	0.16	0.00	6.8	5.74	5.08	1.15	0.16	0.00
8.0	5.0	8.3	6.48	3.22	C.54	0.00	6.3	8.10	8.28	2.52	0.36	0.00
8.0	6.0	9.3	7.20	3.90	0.45	0.00	8.1	9.30	7.80	3.15	1.35	0.30
10.0	5.5	9.1	8.18	4.59	0.66	0.00	8.9	10.81	9.01	3.11	0.49	0.33
10.0	6.5	10.5	9.56	4.99	0.69	0.00	12.1	11.92	7.21	2.77	0.83	0.28
12.0	6.0	9.9	10.20	4.50	0.60	0.00	11.0	12.90	8.40	3.75	0.60	0.00
12.0	7.0	12.1	12.21	5.66	0.65	0.00	15.8	14.80	7.98	3.22	0.77	0.13