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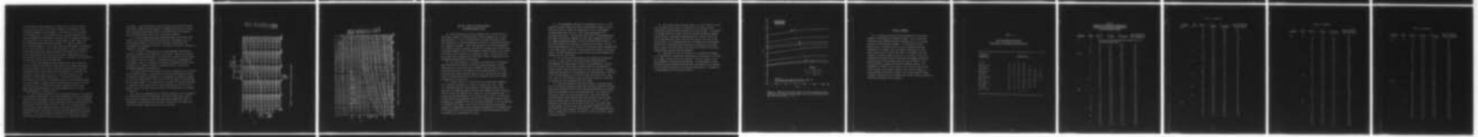

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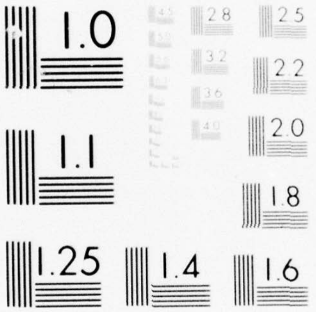

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TILLAMOOK BAY ENTRANCE REFRACTION STUDY, TILLAMOOK, OREGON

by

Lyndell Z. Hales

~~Hydraulics Laboratory~~
U. S. Army Engineer Waterways Experiment Station
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August 1977

Final Report

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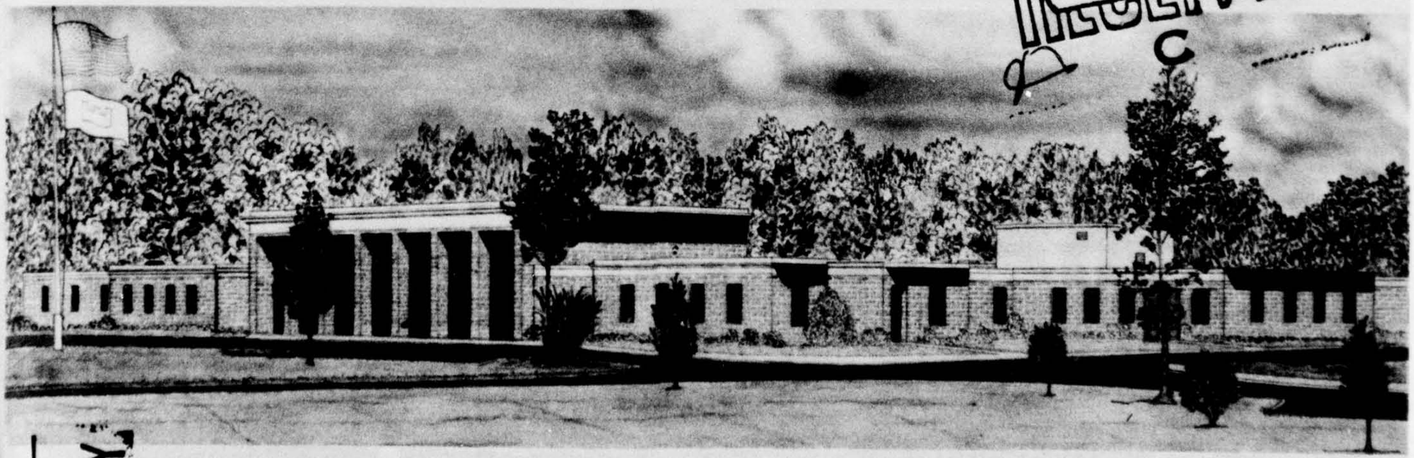

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A numerical wave refraction and shoaling analysis was conducted to transfer wave hindcast data from deep water to the entrance of Tillamook Bay. Also included was a general description of the transformation of surface gravity wave in shoaling water and the effect of tidal currents on gravity wave . No specific conclusions were required of the study but the data was used by the Portland District and North Pacific Division to access navigation hazards at the entrance between the existing north jetty and the proposed south jetty extension.

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PREFACE

Pursuant to telephone conversations of 24 May 77 with personnel of U. S. Army Engineer District, Portland (NPP), the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, conducted a series of water wave refraction analyses for the offshore bar and entrance channel to Tillamook Bay, Oregon, for the purpose of ascertaining the effect of an extension of the south jetty on wave characteristics in the region. Funding for the study was given by NPP Intra-Army order No. E86770091 dated 31 May 1977.

The study was conducted during the period 31 May - 10 June 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. The refraction analyses and preparation of this report were conducted by Mr. L. Z. Hales, Project Engineer.

Director of WES during the conduct of this 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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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
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square miles (U. S. statute)	2.589988	square kilometres
acre-feet	1233.482	cubic metres

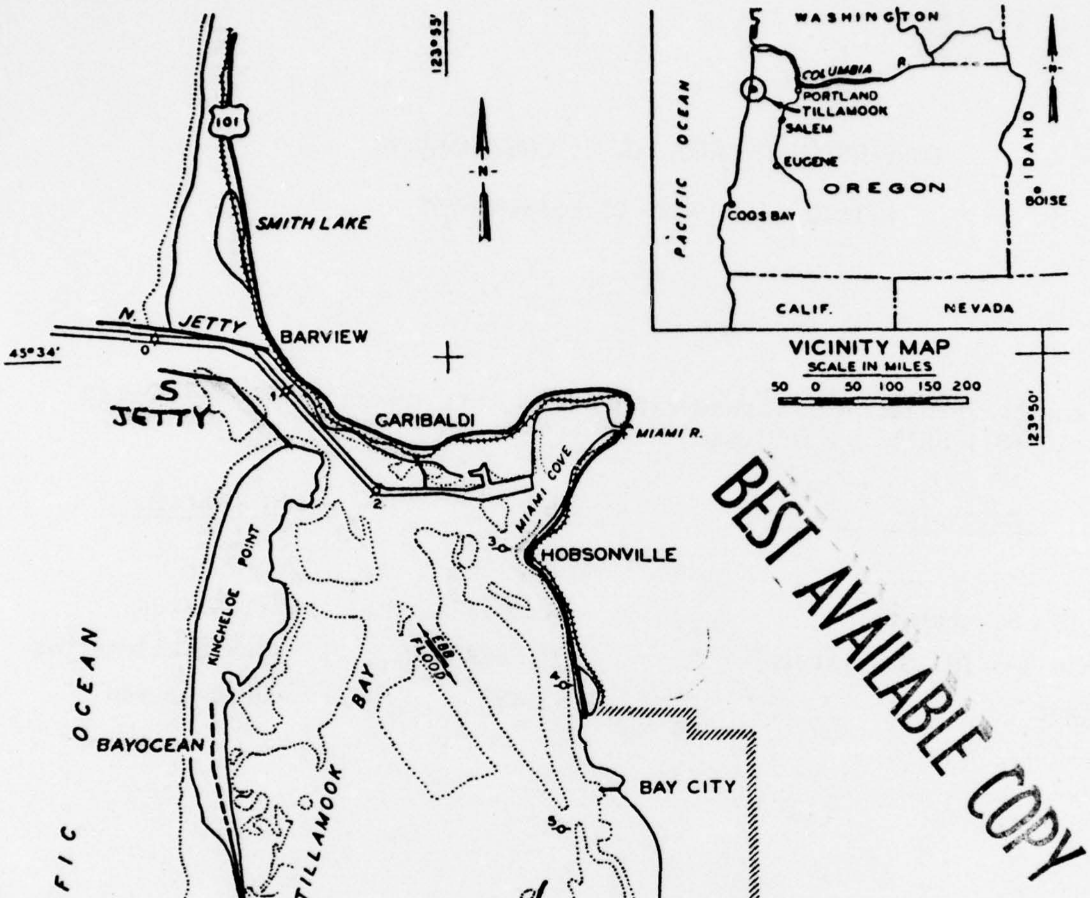

Figure 1. Tillamook Bay and Bar, Oregon

TILLAMOOK BAY ENTRANCE REFRACTION STUDY
TILLAMOOK, OREGON

Part I: Introduction

1. Tillamook Bay, shown in Figure 1, is a tidal estuary about 6 miles long, north to south, and a maximum of 3 miles wide. It covers an area of about 14 square miles at high water and 7 square miles at low water, and has a tidal prism of approximately 48,000 acre-ft. Its entrance, at the north end of the bay, is 47 miles south of the mouth of the Columbia River. Five rivers, all rising in the Coast Range and having a total drainage area of 574 square miles, flow into the bay. The lower valleys of four of the rivers, the Kilchis, Wilson, Trask, and Tillamook, merge to form a broad alluvial plain near the southern tip of the bay on which the city of Tillamook is located. The other river, the Miami, enters the bay on the northeastern side near the town of Garibaldi. The lower 4 miles of the Tillamook River are used extensively for storage and rafting of logs. The bar channel has maintained itself naturally with controlling depths of 12 to 18 ft over a width of 200 ft since the north jetty was built in 1917.

2. The existing project for Tillamook Bay provides for a north jetty about 5700 ft in length; a south jetty extending to about 1700 ft short of the north jetty; a channel through the bar 18 ft deep and of such width as can be practically and economically obtained; a channel 18 ft deep and 200 ft wide from deep water in the bay to Miami Cove, terminating at a turning basin; and initial dredging to a depth of 12 ft of a small-boat basin and an approach thereto at Garibaldi. The existing project also provides for the closure of a breach in Bayocean Peninsula, caused by a storm in 1952, by the construction of a sand and rock-fill dike 1.4 miles in length. This breach was closed in 1956.

3. The north jetty was authorized in 1912 and originally constructed during the period 1914 to 1917 to a length of 5400 ft. It was reconstructed and extended to the authorized length of 5700 ft in 1931-1933. Rehabilitation of the jetty was accomplished in 1956 and again in 1965. The south jetty was authorized by the Rivers and Harbors Act of 27 October 1965, and was constructed in 1969.

Part II: Wave Refraction Analysis for Tillamook Bay Entrance

4. The U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, was requested by the U. S. Army Engineer District, Portland, to prepare wave refraction diagrams for the entrance of Tillamook Bay using existing topography and still-water level of +6 ft mllw. The hydrographic survey data used in the computations were the July 1973 survey outside the entrance supplemented with the latest U. S. Coast and Geodetic Survey charts. Inside the channel the predredging data of October 1973 were used.

5. The wave periods and directions used were the statistics presented for Station 1 in National Marine Consultants Report, "Wave Statistics for three Deep Water Stations Along the Oregon-Washington Coast." The refraction program was run for 1.0-ft waves or unity wave height so that the coefficients obtained could be applied to any wave height up to the breaking limitation. The program was run without the jetties, the data were truncated by manually eliminating the rays intercepted by the existing or extended jetty as applicable. The wave periods and directions believed appropriate to this study are shown in Table 1.

6. The end of the existing south jetty is approximately 1600-1700 ft short of the north jetty, and the proposed extension will be to about 150 ft short of the north jetty. The area of interest is dependent upon where the refraction study indicates the worst conditions to be, but in general should range from the outer bar to the end of the existing south jetty.

7. In this analysis the effects of both reflection and diffraction are neglected. These assumptions are valid except in convergence areas where caustics occur and linear theory does not apply. Therefore, the major assumption in determining the wave height at any point on a wave orthogonal, within the limits of the linear theory, is that no energy is transmitted perpendicular to the orthogonal along the wave crest, in which case the height at any point is given by:

$$H = H_o R_c S_c \tag{1}$$

where

H_o = wave height in deep water
R_c = refraction coefficient
S_c = shoaling coefficient

This assumption has been shown to be reasonable for mild slopes which induce only gradual bending of the wave orthogonals. For areas of extreme refraction, the failure to consider the flow of energy along the wave crests can lead to significant errors in the computed wave height. Since previous research at the Waterways Experiment Station has shown that wave energy will tend to flow along the wave crest in areas of energy concentration, a maximum refraction coefficient of 1.5 was used as the ultimate high value.

8. All wave orthogonals were produced using a grid spacing of 150 ft bounded by latitudes 45°30' and 45°36' and by longitudes 123°56' and 124°00'. A summary of the refraction and shoaling coefficients for those rays which penetrated the entrance between the jetties in the vicinity of the south jetty extension is presented in Table 2. This table also notes whether or not the rays which penetrated between the existing jetties would be blocked by the proposed extension to the south jetty. Of course, the south jetty extension can not reduce the amount of energy entering the entrance channel from about 300° to 360°, and all energy from 157.5° is blocked by the jetty extension. This information can be used to attempt to estimate the improvement in wave conditions and consequently navigation conditions afforded by the jetty extension. The orthogonals were spaced 300 ft apart in deep water and this produced a sufficient intensity of ray coverage to provide an understanding of the effect of the extension of the south jetty on the wave characteristics in the entrance channel near the south jetty entrance. The detailed computer printouts and graphical displays of the wave rays were too numerous to include in this bound report, but were forwarded to Mr. John Oliver, U. S. Army Engineer Division, North Pacific, under separate cover.

Part III: Transformation of Surface Gravity Waves in Shoaling Water

9. The analytical basis of elementary wave theory is the small amplitude application in the development of the mathematical expressions describing the motions of the water surface. This small amplitude theory is the first approximation to the complete theoretical description of wave behavior; however, this first approximation is rewarding in that it yields a maximum of useful information for a minimum effort expended. In many practical situations the error involved with the use of this theory is negligible, while in other cases the phenomenon of interest may not be investigated by this method and other wave theories must be applied.

10. The small amplitude wave theory is based on the assumptions that all motions are so small that the integrated equation of motion, which was developed under the further assumptions that the flow is irrotational and the fluid density is invariant, may be linearized. This implies that the square of the velocity components is negligible in comparison with other terms remaining in the mathematical development, and thus allows the free surface boundary conditions to be linearized. In particular, terms involving the wave amplitude to the second and higher orders are considered negligible.

11. If the wave amplitude is relatively large, the small amplitude considerations are not valid; and it is necessary to retain higher order terms in any theory in order to obtain an accurate representation of the wave motion. In many situations it is the extremely nonlinear waves which are of primary importance.

12. The small amplitude wave theory is assumed valid for all ranges of relative water depth, d/L. This is possible due to the assumption of relative smallness of the parameters H/d and H/L compared with unity. Finite amplitude wave theories are complicated due to the relative important of these additional parameters, and it is difficult to derive a comprehensive theory in which both of these parameters can assume arbitrary values within certain ranges. The standard approach has been

to regard one of these parameters as small, and to develop a theory valid for finite values of the other parameter. In deep water, the important parameters are wavelength, L, and the ratio of wave height to wavelength, H/L. In very shallow water, the wave conditions are nearly independent of wavelength, or period, and the important parameters are water depth, d, and the ratio of wave height to water depth, H/d. In a range intermediate to these two there is a region in which the ratios of wave height to water, depth, H/d, and wave height to wavelength, H/L, are both important. It has been found that for this intermediate region (the coastal zone where d/L varies from around 1/10 to 1/50), a wave theory expressed in terms of the Jacobian elliptic function, cn, is most valid; hence, the term cnoidal which is analogous to the sinusoidal applications of the small amplitude theory.

13. While wave sampling records indicate that the wave profiles observed in nature very nearly fit the cnoidal wave shape predictions, the cnoidal theory still has not achieved the position of a tool for engineers which one would expect from the demand for a consistent and reasonably accurate long wave theory. One of the reasons is the complexity of the elliptic function, cn. Unlike the sinusoidal wave theory, the velocity of propagation and thus the wavelength depends on the wave height. Another reason is probably the fact that it is not entirely possible to determine how the main parameters such as wave height and wavelength change as the wave propagates over a varying bottom topography, or shoaling water.

14. One limiting condition of the cnoidal wave theory is the solitary wave in shallow water which is the case independent of period or wavelength with the entire wave profile above the mean waterline. A second limiting condition is the sinusoidal wave in deep water with 50% of the wave profile above and 50% below the mean waterline. Thus, it is evident that as surface gravity waves propagate and shoal from deep to shallow water, an increasingly larger percentage of the wave profile appears above the mean waterline. This is particularly important in determining the distance from the mean waterline to the deck elevation of an offshore structure,

for example. Equally important is the distance from the mean waterline to the wave trough from the standpoint of shipping and safety to navigation as minimum channel depths must be maintained across the offshore bars which develop near tidal inlets and estuary entrances.

15. For the completely general condition based on the cnoidal wave theory, it has been found that the wave profile is dependent upon the dimensionless parameter involving the wavelength, wave height, and water depth, and expressed as L^2H/d^3. This general condition is displayed graphically in Figure 2.

16. In order to determine the wave shape expected for particular locations a specific water depth must be assigned. When this particular water depth has been determined, it is possible to express the wavelength, L, in terms of the wave period, T, associated with this wavelength and water depth. Then it is possible to display the completely general curve of Figure 2 as a family of curves of constant period, T, versus the independent parameter wave height, H.

17. Because the entrance channel across the offshore bar at Tillamook Bay and Harbor, Oregon, is maintained at an 18 ft mllw depth and because the mean tide range is approximately 6 ft (indicating a probably maximum water depth at high tide of 24 ft across the bar), Figure 3 was developed for this water depth. It is important to note that the larger water depth is required as this implies that a larger percentage of the total wave height is below the mean waterline, and thus the significance on shipping is apparent.

18. Since the deepwater wave statistics frequently used by engineers are presented in terms of significant wave period and height, Figure 3 may be used in conjunction with these statistical tables to obtain an estimation of the percentage of time that a particular water depth will exist for the wave climate peculiar to this location.

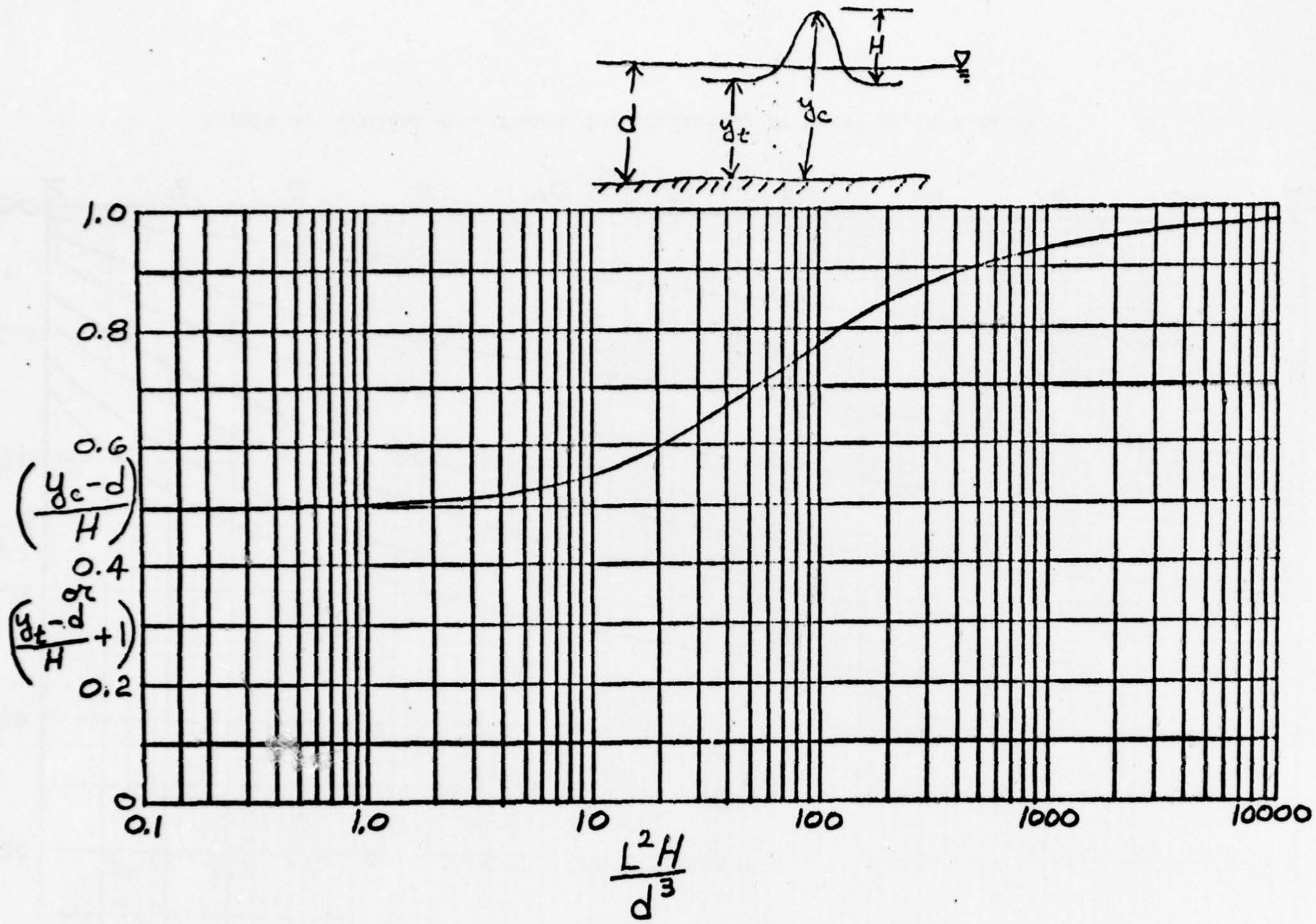

Figure 2. Cnoidal wave theory for general conditions.

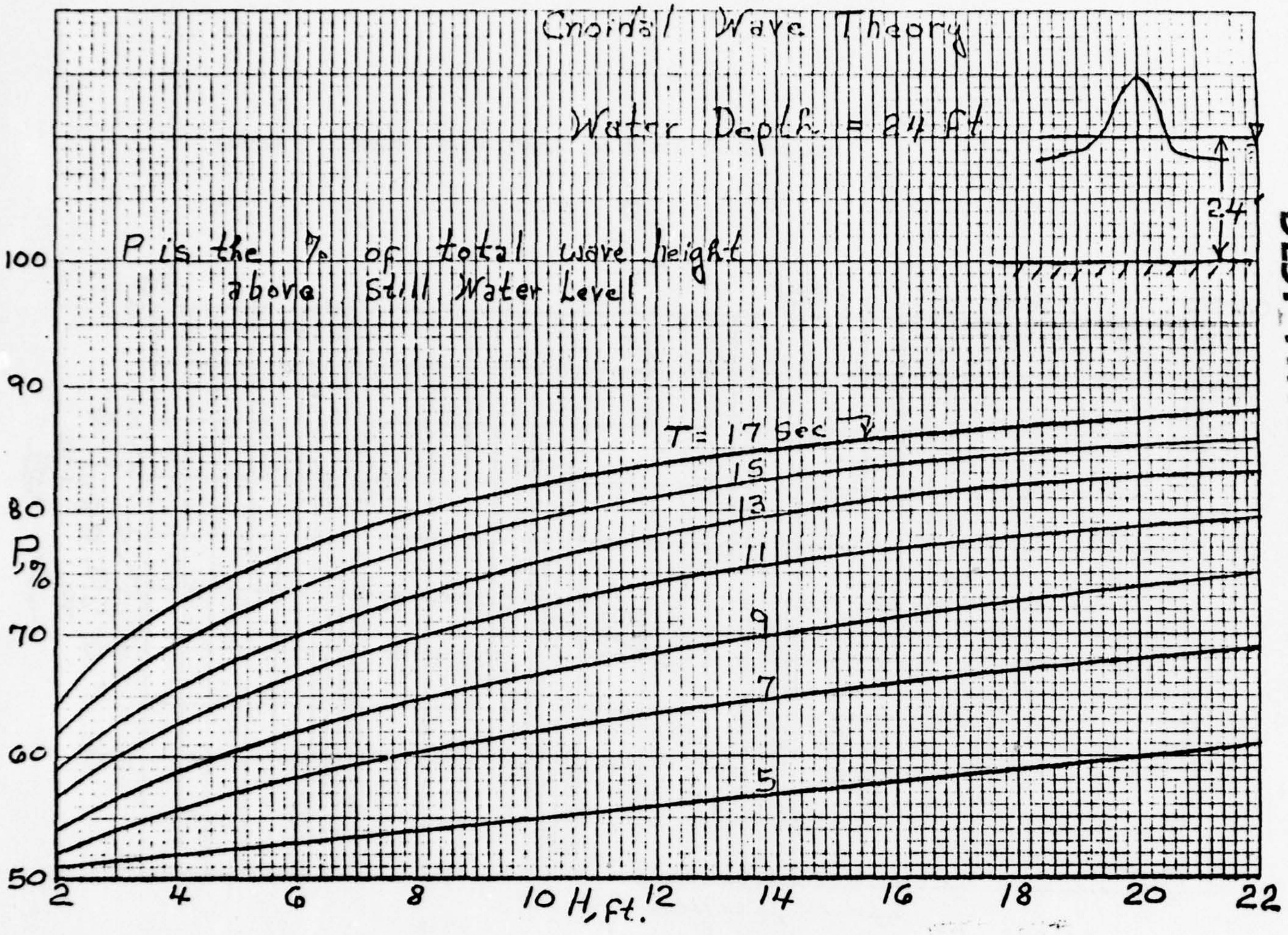

Figure 3. Cnoidal wave theory for conditions at water depth = 24 ft.

Part IV: Effect of Tidal Currents on Surface Gravity Waves

19. When surface gravity waves propagate from a region of still water into a region of streaming water, certain changes occur in their characteristics. It is an observed fact that waves traveling in the same direction as a current experience an increase in length and celerity and a decrease in height. Waves that propagate in a direction opposed to a current increase in height and decrease in length and celerity until a limiting steepness occurs which depends on both the initial wave characteristics and the strength of the opposing current. At this point the waves break and a large portion of the wave energy is dissipated in the turbulence associated with the breaking.

20. At tidal entrances to estuaries, the current will alternately oppose and flow with the waves as waves propagate through the inlet. During ebb flow, waves entering the estuary will have their steepness increased and hazards to navigation are accordingly produced. In the alternate case, waves traveling with the tidal current will have their lengths increased and this has a direct influence on the rate of energy propagation into the estuary.

21. Coastal inlets in a natural state are subjected to opposing forces which alternately try to close or enlarge the inlet. Since it is desirable that the inlet location and geometry remain fixed, decisions are frequently made that corrective engineering works be undertaken to ensure the stability of a tidal inlet on an erodible coast. To prevent the lateral movement of the coastal inlet, jetties are often constructed which extend seaward from the shore and become essential to the operation of a dependable inlet for navigation purposes, as at the entrance to Tillamook Bay, Oregon. Since both a jetty system and maintenance dredgin of a navigation channel through the offshore bar are required here, the characteristics of the surface gravity waves being propagated toward Tillamook Bay are significantly altered.

22. An experimental study has been conducted at the U. S. Army Engineer Waterways Experiment Station concerning the manner in which nonuniform currents affect the characteristics of a superimposed surface gravity wave train at a first order approximation of a prototype tidal inlet. The work was conducted in a three-dimensional wave basin in which was simulated a tidal inlet through which could be created nonuniform currents in both an ebb and flood direction. For the flood condition the current was required to build up on its own accord from essentially zero velocity in the ocean, reach a maximum value in the inlet throat, and decay to essentially zero velocity in the bay region. The ebb condition was similar except the current opposed the direction of the wave motion.

23. For a variety of steady-state flow conditions through the facility, a range of wave trains with initial characteristics representative of those found in nature were superimposed. Measurements of velocity, wave height, and wavelength were determined at selected points along the center-line axis of the facility. Multiple regression analysis of the experimental data indicated that in addition to the current parameter, the relative depth and initial wave steepness, H/L, are statistically highly significant parameters affecting the changes in both wavelength and wave height.

24. Visual observation of the ocean region of the experimental facility during the testing program under ebb flow conditions revealed that an area oceanward of the inlet entrance experienced the greatest degree of alteration to the wave characteristics. The location of this point varied with the individual waves, and with increasing current velocity would progress away from the inlet into the ocean with the shorter waves being affected the most severely. It was difficult to observe the alterations to the long waves under small current values, as these waves could propagate through the current field with only minor dynamic interactions. The instrumentation was, however, sufficiently accurate for detecting even the smaller changes in the wave height.

25. The shorter waves were much easier to detect visually as the entire particle motion field was affected by the current and the interaction produced dramatic changes in the wave heights. The greatest alterations would occur before the waves reached the area of highest current velocity, and with increasing current a section of the wave crest would physically shear from the wave train at the zone of ebb current flow. This sheared section was restrained in its propagation toward the inlet by the current convecting it downstream, and would begin to spill down the front of the wave section with the resulting foaming action noted by other researchers.

26. The effect of the ebb current on the incoming wave heights is as significant as refraction and shoaling in the region of the ocean bar located oceanward of the bay entrance. However, because of the many parameters interacting simultaneously, an experimental testing program of each particular prototype under consideration is at present the only effective means of evaluating the phenomenon. An example of the experimental data is shown in Figure 4.

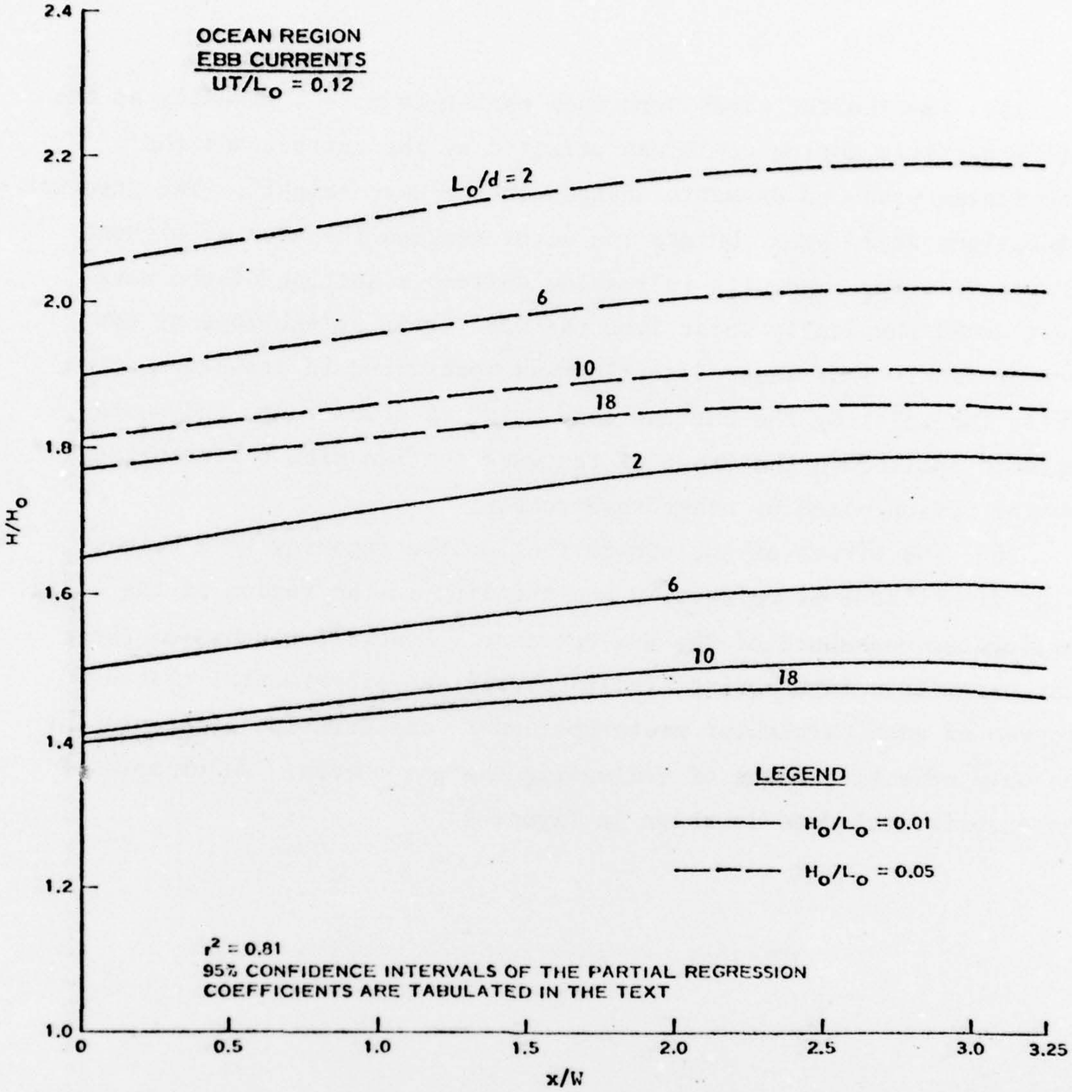

Figure 4. Multiple regression analysis of the experimental data expressing the change in wave height in the ocean region under an ebb current with $UT/L_o = 0.12$

Part V: Summary

27. A refraction study has been performed for the entrance channel to Tillamook Bay, Tillamook, Oregon. Ten incident wave directions were considered and wave periods from 5 to 17 seconds were used in two-second increments. A discussion of surface gravity waves in shoaling water is given including sufficient information to estimate crest and trough elevations for finite height waves based on cnoidal wave theory. The effect of tidal currents on surface gravity waves also is discussed. Sufficient information has been provided to estimate the energy entering the entrance channel for existing conditions and the effect of the jetty extension on energy entering the entrance channel. The information contained in this report can be used, in concert with a wave climate, to estimate the percent of time that ships can safely navigate the entrance channel (with some assumptions about clearence required and vessel draft) for both the existing conditions and with the proposed jetty extension.

Table 1

Wave Directions and Periods Significant to Tillamook Bar and Entrance

Direction of Approach	Period, sec						
N (0°)	5,	7,	9,	11			
NNW (337.5°)	5,	7,	9,	11,	13		
NW (315°)	5,	7,	9,	11,	13,	15,	17
WNW (292.5°)	5,	7,	9,	11,	13,	15,	17
W (270°)	5,	7,	9,	11,	13,	15,	17
WSW (247.5°)	5,	7,	9,	11,	13,	15,	17
SW (225°)	5,	7,	9,	11,	13,	15	
SSW (202.5°)	5,	7,	9,	11,	13,	15	
S (180°)	5,	7,	9,	11,	13,	15	
SSE (157.5°)	5,	7,	9,	11			

Table 2

Effects of South Jetty Extension on Refraction and Shoaling Coefficients in the Entrance Channel

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
0	5	(No rays entered the entrance channel for this period and direction.)			
	7	11	1.5	0.9	No
	9	14	1.5	1.0	No
	11	15	1.5	1.1	No
337.5	5	6	0.9	0.9	No
		7	0.9	0.9	No
	7	8	1.5	1.0	No
		9	0.8	1.0	No
	9	9	0.9	1.1	No
		10	1.0	1.0	No
	11	10	1.5	1.0	No
		11	0.9	1.0	No
		12	1.5	1.2	No
	13	10	1.5	1.2	No
		11	1.5	1.2	No
		12	1.5	1.2	No
		13	0.8	1.2	No
315	5	7	1.2	0.9	No
		8	0.9	0.9	No
	7	8	1.0	0.9	No
		9	0.8	1.0	No
	9	9	0.9	1.0	No
		10	0.7	1.1	No
	11	10	0.8	1.1	No
	13	10	0.8	1.2	No
		16	1.5	1.2	No
	15	10	0.8	1.2	No
		16	1.5	1.3	No
	17	16	1.5	1.3	No
		17	1.5	1.3	No

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked By Jetty Extension
292.5	5	7	0.8	0.9	No
		8	1.5	0.9	No
		9	1.5	0.9	No
		10	1.5	0.9	Yes
		11	1.5	1.0	Yes
	7	7	0.9	0.9	No
		8	1.5	1.0	No
		11	1.5	1.0	No
	9	7	0.7	1.0	No
		8	1.4	1.1	No
		12	0.8	1.0	No
		13	1.5	1.1	Yes
	11	7	0.8	1.1	No
		8	0.8	1.2	No
		9	1.5	1.1	No
		12	0.8	1.1	No
		13	0.7	1.2	No
	13	8	0.9	1.2	No
		9	1.5	1.2	No
		12	0.7	1.2	No
		13	1.3	1.2	No
	15	8	0.8	1.3	No
		12	0.7	1.2	No
		13	1.5	1.3	No
	17	8	0.9	1.3	No
		12	0.7	1.3	No
		13	0.6	1.5	No
270	5	7	0.9	0.9	No
		8	1.0	0.9	No
		9	0.8	0.9	No
		10	0.9	0.9	Yes
		12	1.5	0.9	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
270	7	5	1.5	1.0	No
		6	1.5	0.9	No
		7	1.5	1.0	No
		9	0.7	1.0	No
		10	1.5	0.9	No
		11	1.5	1.0	Yes
		12	1.5	1.0	Yes
	9	6	0.8	1.0	No
		7	1.2	1.0	No
		9	1.5	1.1	No
		10	1.5	1.2	Yes
		11	1.5	1.1	Yes
		12	1.5	1.1	Yes
		13	1.5	1.2	Yes
	11	4	0.7	1.2	No
		5	1.1	1.1	No
		6	1.2	1.2	No
		7	0.6	1.2	No
		9	1.1	1.1	No
		10	1.0	1.3	Yes
		11	1.5	1.2	Yes
		12	1.5	1.2	Yes
		13	1.3	1.3	Yes
	13	4	1.5	1.2	No
		5	1.0	1.1	No
		6	1.5	1.2	No
		7	0.5	1.1	No
		9	1.5	1.2	No
		10	1.0	1.2	Yes
		11	1.5	1.2	Yes
		12	1.5	1.3	Yes
		13	1.5	1.4	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
270	15	4	1.5	1.3	No
		5	1.5	1.2	No
		6	1.5	1.3	No
		7	0.5	1.2	No
		9	1.5	1.3	No
		10	0.9	1.3	Yes
		11	1.5	1.3	Yes
		12	1.5	1.3	Yes
		13	1.5	1.4	Yes
	17	4	1.3	1.3	No
		6	1.5	1.4	No
		9	1.5	1.3	No
		10	0.9	1.4	Yes
		11	1.5	1.3	Yes
		13	1.5	1.5	Yes
247.5	5	9	1.1	0.9	No
		10	1.0	0.9	No
		11	1.5	0.9	No
		12	1.5	0.9	No
		13	1.1	0.9	Yes
		14	1.5	1.0	Yes
		15	1.5	0.9	Yes
	7	9	1.0	0.9	No
		10	1.5	1.0	No
		11	1.5	1.0	No
		12	1.5	0.9	Yes
		13	1.5	0.9	Yes
		14	1.5	1.0	Yes
		15	1.5	1.0	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
247.5	9	4	1.3	1.0	No
		8	1.0	1.0	No
		9	1.0	1.0	No
		10	1.5	1.0	No
		11	1.5	1.0	No
		12	1.3	0.9	Yes
		13	1.5	1.0	Yes
		14	0.9	1.1	Yes
	11	3	0.7	1.1	No
		8	1.0	1.1	No
		9	1.5	1.1	No
		10	1.5	1.1	No
		11	1.5	1.0	Yes
		12	1.5	1.2	Yes
		13	1.5	1.2	Yes
		14	1.5	1.2	Yes
	13	3	1.5	1.2	No
		8	1.1	1.3	No
		9	1.5	1.2	No
		10	1.5	1.2	No
		11	1.5	1.1	Yes
		12	1.5	1.3	Yes
		13	1.5	1.3	Yes
	15	3	0.9	1.2	No
		7	0.7	1.2	No
		8	1.5	1.4	No
		9	1.5	1.3	No
		10	1.5	1.3	No
		11	1.5	1.5	Yes
		12	1.5	1.4	Yes
		13	1.5	1.5	Yes

Table 2, continued

θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays blocked by Jetty Extension
247.5	17	3	1.5	1.3	No
		7	0.8	1.3	No
		8	1.5	1.5	No
		9	1.5	1.3	No
		10	1.5	1.3	Yes
		11	1.5	1.2	Yes
		12	1.5	1.5	Yes
		13	1.5	1.2	Yes
225	5	7	1.0	0.9	No
		8	1.1	1.0	No
		9	1.5	1.0	Yes
		10	1.2	1.0	Yes
		11	0.9	0.9	Yes
		12	1.1	0.9	Yes
		13	1.2	1.0	Yes
	7	5	1.1	0.9	No
		6	1.0	0.9	No
		7	1.5	0.9	No
		8	1.5	0.9	Yes
		9	1.0	1.0	Yes
		10	1.0	0.9	Yes
		11	0.9	1.0	Yes
	9	3	1.1	1.0	No
		4	1.1	1.0	No
		5	1.5	0.9	No
		6	1.5	1.0	No
		7	1.0	0.9	Yes
		8	1.1	1.1	Yes
		9	1.2	1.0	Yes
		10	1.5	1.0	Yes

Table 2, continued

θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
225	11	2	0.9	1.1	No
		3	1.5	1.1	No
		4	1.5	1.3	No
		5	1.5	1.1	Yes
		6	1.3	1.0	Yes
		7	0.9	1.2	Yes
		8	1.5	1.0	Yes
	13	1	1.3	1.1	No
		2	1.1	1.1	No
		3	1.5	1.2	No
		4	1.5	1.1	No
		5	1.5	1.2	Yes
		6	0.8	1.2	Yes
		7	1.5	1.2	Yes
		8	1.5	1.2	Yes
	15	1	1.4	1.2	No
		2	1.0	1.2	No
		3	1.5	1.3	No
		4	1.5	1.2	No
		5	1.5	1.1	Yes
		6	0.7	1.3	Yes
		7	1.5	1.4	Yes
		8	1.5	1.2	Yes
202.5	5	10	1.1	0.9	No
		11	1.0	0.9	Yes
		12	1.2	1.0	Yes
		13	1.0	0.9	Yes
		14	1.1	0.9	Yes
		15	0.9	0.9	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
202.5	7	6	0.9	0.9	No
		7	1.4	0.9	No
		8	1.0	0.9	Yes
		9	1.5	0.9	Yes
		10	1.0	1.0	Yes
		11	0.8	0.9	Yes
		12	1.1	0.9	Yes
	9	4	0.9	1.0	No
		5	1.5	1.0	No
		6	1.5	1.0	Yes
		7	0.7	1.1	Yes
		8	0.9	1.1	Yes
		9	1.3	1.1	Yes
		10	0.8	0.9	Yes
	11	2	1.5	1.0	No
		3	1.5	1.0	No
		4	1.5	1.0	Yes
		5	1.5	1.0	Yes
		6	1.1	1.1	Yes
		7	1.5	1.0	Yes
		8	1.5	1.1	Yes
	13	1	1.1	1.2	No
		2	0.9	1.2	No
		3	1.5	1.1	No
		4	1.5	1.1	Yes
		5	0.8	1.2	Yes
		6	1.5	1.3	Yes
		7	0.7	1.3	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked By Jetty Extension
202.5	15	1	1.1	1.2	No
		2	1.3	1.1	No
		3	1.5	1.5	Yes
		4	1.5	1.3	Yes
		5	0.8	1.3	Yes
		6	1.5	1.4	Yes
		7	1.0	1.1	Yes
180	5	11	0.5	0.9	No
	7	4	1.5	1.0	No
		5	1.5	1.0	Yes
		6	1.0	1.0	Yes
		7	0.9	1.0	Yes
	9	15	0.6	1.0	No
		16	1.3	0.9	Yes
		17	1.2	0.9	Yes
		18	0.4	1.1	Yes
		20	0.7	1.1	Yes
		24	0.2	1.0	No
	11	12	1.3	1.0	No
		14	1.9	1.1	Yes
		15	0.5	1.1	Yes
		16	1.5	1.2	Yes
		17	1.2	1.2	Yes
		24	0.2	1.1	Yes
	13	9	1.1	1.2	No
		10	0.8	1.1	No
		11	0.8	1.1	No
		12	1.5	1.2	Yes
		13	1.5	1.0	Yes
		14	1.1	1.2	Yes
		15	0.3	1.3	Yes
		24	0.2	1.2	Yes

Table 2, continued

Θ (degree)	T (sec)	Ray No.	$(R_c)_{max}$	$(S_c)_{corres}$	Rays Blocked by Jetty Extension
180	15	9	1.5	1.2	No
		10	1.5	1.2	No
		11	0.7	1.1	Yes
		12	1.7	1.3	Yes
		13	1.5	1.3	Yes
		14	1.1	1.3	Yes
		24	0.2	1.3	Yes
157.5	5	6	0.5	0.9	Yes
	7	5	0.5	1.0	Yes
	9	4	1.5	1.0	Yes
		5	0.5	1.1	Yes
	11	3	0.6	1.1	Yes
		4	1.5	1.0	Yes
		5	0.5	1.2	Yes

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