CHAPTER 96

SHIP WAVES IN SHOALING WATERS

J. W. Johnson
University of California
Berkeley

ABSTRACT

Models of two types of vessels were towed at various speeds in water of uniform depth. On one side of the sailing line the ship waves were allowed to move over beaches of various slopes. The wave heights were measured and compared at two points equidistant from the sailing line--patterns were determined by photographs.

INTRODUCTION

Several studies have been made at the University of California to determine the characteristics of waves generated by moving ships. The initial studies by Johnson (1)* were concerned with model tests in the laboratory as well as some field tests with a power boat. More recently Sorensen (2,3) measured the waves generated by five different types of ships moving in the Oakland Estuary in California. Sorensen (3,4) and Moffitt (5) also determined the surface contours of a ship-wave system by stereophotography of a ship model moving at various speeds through water of constant depth. To extend the work of Sorensen (2,3), Duncan Hay has determined by model studies the wave characteristics of several large commercial type ships, barges, tugs, etc., moving at various speeds in shallow water of various uniform depths. Hay's data are presented in the foregoing chapter of this publication.

A typical ship-wave pattern consists of diverging waves and transverse waves. These waves form a constant pattern and meet to form a locus of cusps with an angle to the sailing line. In deep water this angle is about 19° 28' and becomes greater in shallow water. The maximum wave height occurs when the locus of cusps passes a measuring point. It has been customary to refer to the maximum wave height H_{max}, as the maximum vertical distance between any given wave trough and the following crest. The magnitude of the maximum wave for a given ship is a function of the ship speed, the water depth, and the distance from the sailing line. Some information on maximum wave heights for several types of ships, as determined by both laboratory and field studies, are presented below.

---

*See References

SHIP WAVE MEASUREMENTS

An indication of the general order of magnitude of the height and period of the maximum wave generated by boats from 3 to 343 tons is given in Table 1. These data are derived from the measurements of Sorensen (1) in the Oakland Estuary in which a depth of approximately 35 ft. existed. The maximum wave height and half period is given at distances of 100 and 500 ft. from the sailing line with the boats moving at 10 knots. The length, beam, and draft of each vessel is also presented. It is to be noted that the difference in wave height between the extremes of size of vessel is relatively small for the depth of water existing in the tests. As discussed elsewhere (1) the critical factor governing the maximum wave height is the ratio of draft to depth, a factor which is not readily apparent in the comparisons shown in Table 1.

The data presented in Table 1 pertain to ship waves in water of uniform depth. To obtain information on the transformation of such waves as they move into shoaling water, a series of laboratory measurements were made with models of the Mariner Class cargo ship and a barge similar to that used by Hay but to a 1:96 scale. The characteristics of these models are described in Table 2. Cross sections of the sloping beaches used in the tests are shown in Fig. 1. The models were towed at various

TABLE 1. WAVES GENERATED BY VARIOUS BOATS OPERATING AT 10 KNOTS IN THE OAKLAND ESTUARY (depth = approx. 35')

Boat	Length (ft)	Beam (ft)	Draft (ft)	Displacement (tons)	Distance from sailing line			
					100 ft		500 ft	
					H_{max} ft	T/2 sec	H_{max} ft	T/2 sec
Cabin Cruiser	23	8.25	1.66	3	1 1	-	0.8	-
Coast Guard Cutter	40	10	3.5	10	1.6	1.0	1.0	1.0
Tugboat	45	13	6	29	1.6	1.2	0.9	1.2
Fishing Boat	64	12.8	3	35	1.8	1 0	0.7	1.0
Fireboat	100	28	9-12	343	1.6	1.3	1.0	1.3

TABLE 2. SHIP CHARACTERISTICS

Type	Prototype Dimensions				Model Length Scale
	Displacement (tons	Length (ft)	Beam (ft)	Draft (ft)	
Mariner Class Cargo	16,500	566	74	24	1 96
Barge	5,400	263	55	14	1·96

TABLE 3. TEST CONDITIONS FOR WAVES ON SLOPING BEACHES (PROTOTYPE DIMENSIONS)

Model	Bench Slope								
	1 10			1 5			Composite		
	d_1 (ft)	d_6 (ft)	x (ft)	d_1 (ft)	d_6 (ft)	x (ft)	d_1 (ft)	d_6 (ft)	x (ft)
Cargo Ship	60	5	1006	60	15	725	56	8	932
Barge	42	3.5	882	42	10.5	665	56	8	932

speeds in water of various depths, and the wave heights were recorded at equi-distances on the two sides of the sailing line. On one side (sta. 1) the water was of uniform depth, and on the other side (sta. 6) the waves were allowed to pass over beaches of three different slopes. The water depths at stations 1 and 6 and the distances of these stations from the sailing line are summarized in Table 3. The results of the various wave measurements with the two models are presented in Figures 2 and 3. It is evident from Fig. 2 that at the lower speeds the waves from the cargo ship appear to be less on the 1:5 and 1:10 slopes than in water of uniform depth--apparently as a result of refraction effects. At the highest speeds the waves are as high or greater on the sloping beaches than in water of uniform depth. Because of the relatively low maximum speed of the barge, the wave heights on the sloping beach are always less than in water of uniform depth. In all instances it should be noted that, even though the waves on the beaches may be lower than in the deeper water on the opposite side of the sailing line, the waves will peak up and break on the shoreline.

Some indication of the character of the wave pattern in the nearshore area is illustrated by Fig. 4 which shows contours of the wave surfaces resulting from the passage of the Mariner Class ship model. These contours were obtained by stereophotogrammetric analysis from stereophotographs taken as the ship waves moved from water of uniform depth onto a 1:10 beach. The dimensions shown in Fig. 4 are model values. In prototype terms, this figure shows that a Mariner Class cargo ship of 16,500 tons displacement moving at 19 knots in water 48 ft. deep along a sailing course parallel to and 890 ft. from the waters edge will give the pattern shown in Fig. 4 as the waves move over a 1:10 beach. The ship's stern is approximately 960 ft. ahead of point A (Fig. 4), and the height of the breaking wave crest at point B is 10 ft. above the still-water level. The length of shoreline covered in Fig. 4 is approximately 500 ft.

To supplement the wave patterns obtained by stereophotogrammetry, illustrated by Fig. 4, ripple-tank photographs obtained by towing a 1:576 scale model of the Mariner Class ship at various speeds were obtained in the ripple tank at the University of California and are shown in Figs. 5 and 6. The technique of obtaining these photographs is described elsewhere by Laitone (6). These photographs show the waves as they move from water of uniform depth onto beaches with slopes of 1:5 (Fig. 5) and 1:10 (Fig. 6). Two views of the waves are presented for each ship speed to permit a detailed evaluation of the entire wave system. The wave patterns are shown for four different values of the parameter,

$$\lambda = C/C_o$$

where C is the speed of the ship and C_o is the velocity of a wave in shallow water; i.e., $C_o = \sqrt{gd}$, where g is the acceleration of gravity, and d is the water depth. Examination of the various photographs shows the obvious change in wave height and geometry of the wave pattern with ship speed. Also of interest is the large bow waves that exist when the critical speed of $\lambda = 1$ is exceeded. The nature of the refraction and reflection of this bow wave, as well as the following smaller waves, from the sloping sides also is of interest.

SUMMARY

The above data provide some measure of the heights of waves resulting from the passage of typical ships moving at various speeds near sloping shorelines. The magnitude of such waves when ships travel at relatively high speeds obviously may create hazardous conditions to unobserving users of the shoreline. Floating equipment and docks along a shoreline also are subject to damage.

ACKNOWLEDGMENT

The model experiments described herein were conducted on a project sponsored by the U. S. Army Coastal Engineering Research Center, Washington, D. C.

REFERENCES

1. Johnson, J. W., "Ship Waves in Navigation Channels," *Proc. Sixth Conference on Coastal Engineering,* 1958, pp. 666-690.

2. Sorensen, Robert M., "Investigation of Ship-Generated Waves," *Journal of the Waterways and Harbors Division,* A.S.C.E., February 1967, pp. 85-99.

3. Sorensen, Robert M., "Waves Generated by a Moving Ship," *Shore and Beach,* Vol. 35, No. 1, April 1967, pp. 21-25.

4. Sorensen, Robert M., "Stereophotogrammetric Analysis of Wave Surfaces," *Journal of the Hydraulics Division,* A.S.C.E., January 1968, pp. 181-194.

5. Moffitt, F. H., "Wave Surface Configuration," *Photogrammetric Engineering,* February 1968, pp. 179-188.

6. Laitone, E. V., "A Study of Transonic Gas Dynamics by the Hydraulic Analogy," *Journal of the Aeronautical Sciences,* Vol. 19, No. 4, April, 1952, pp. 265-272.

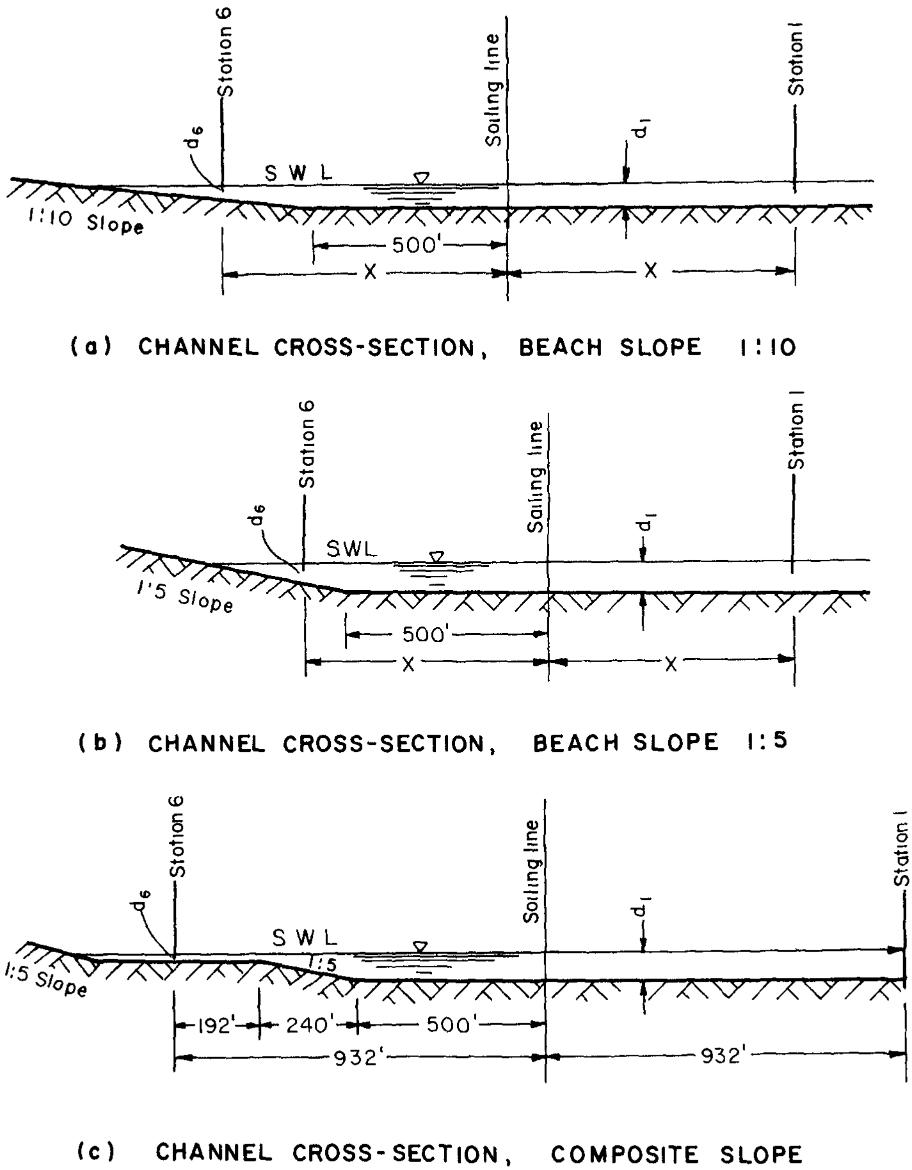

Fig. 1 - Channel cross sections used in model investigations of ship waves on sloping beaches (prototype dimensions).

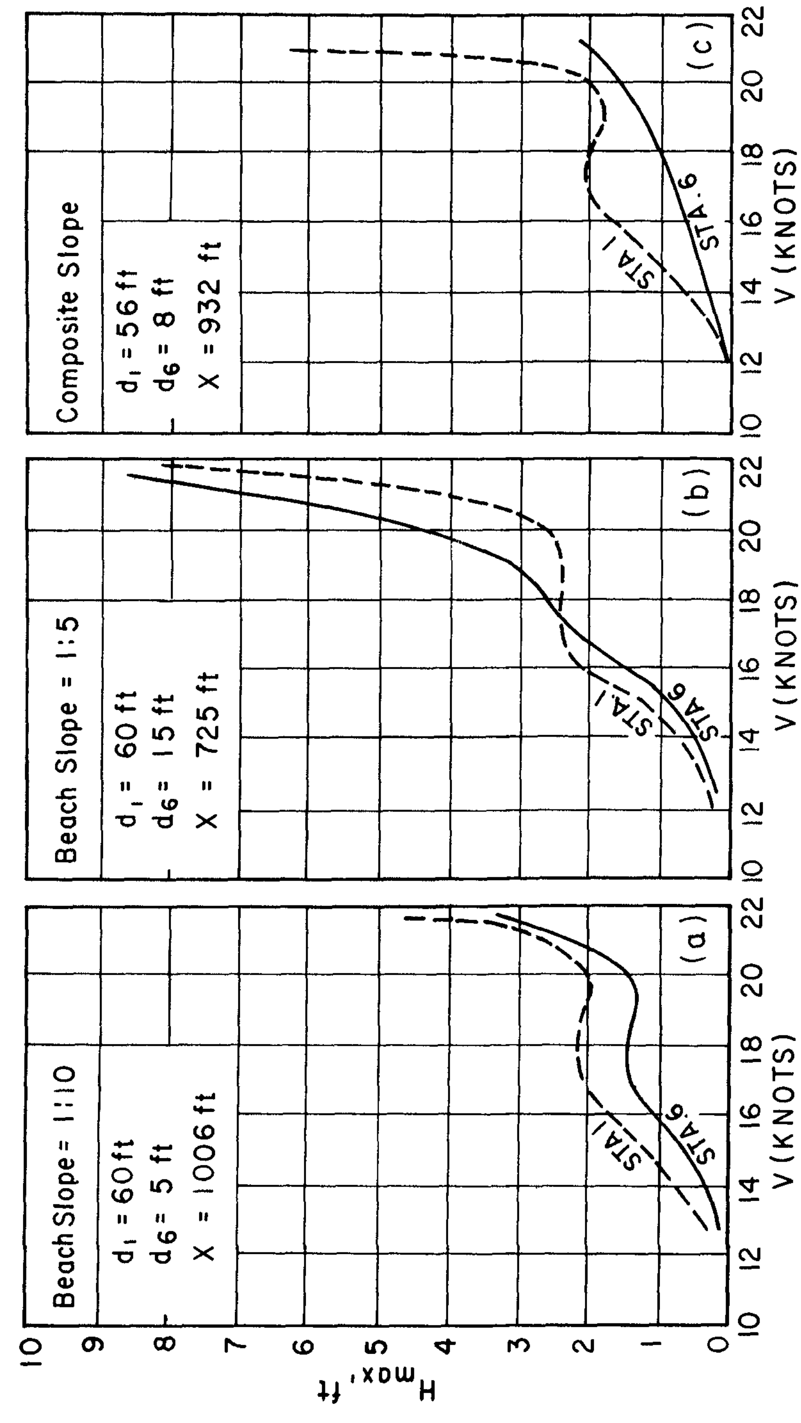

Fig. 2 - Maximum wave heights generated by a Mariner Class Cargo ship. Ship waves measured in water of uniform depth (sta. 1) and over a sloping beach (sta. 6).

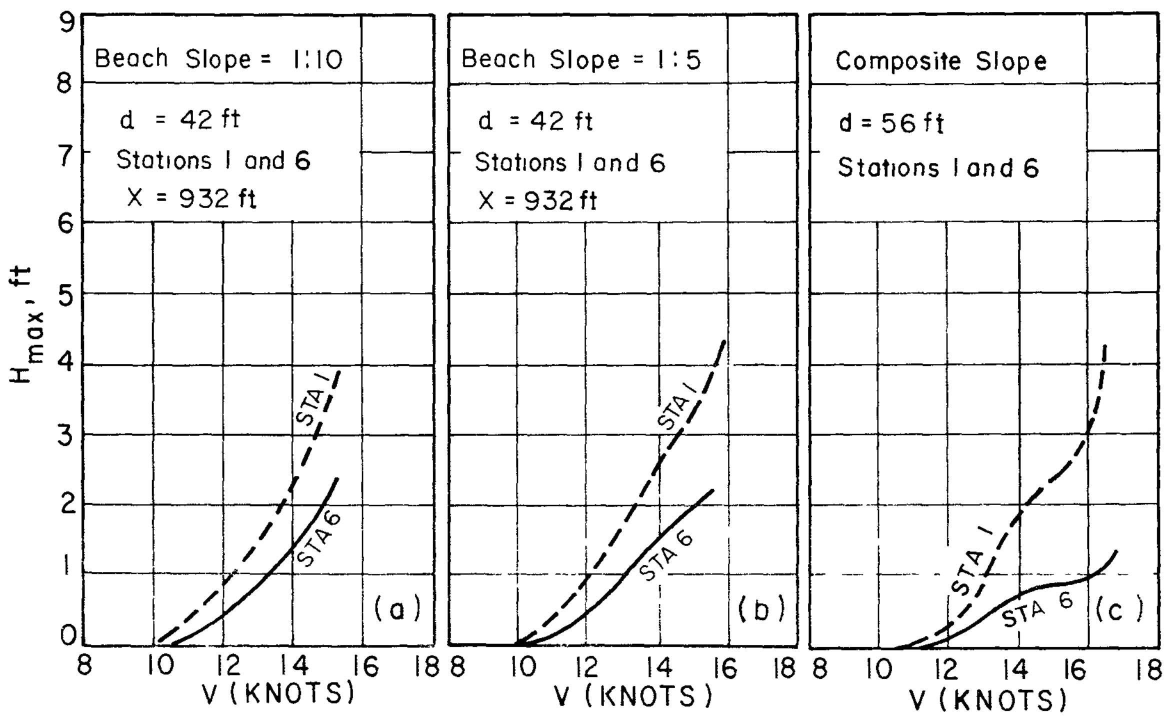

Fig. 3 - Maximum wave heights generated by a Barge. Ship waves measured in water of uniform depth (sta. 1) and over a sloping beach (sta. 6).

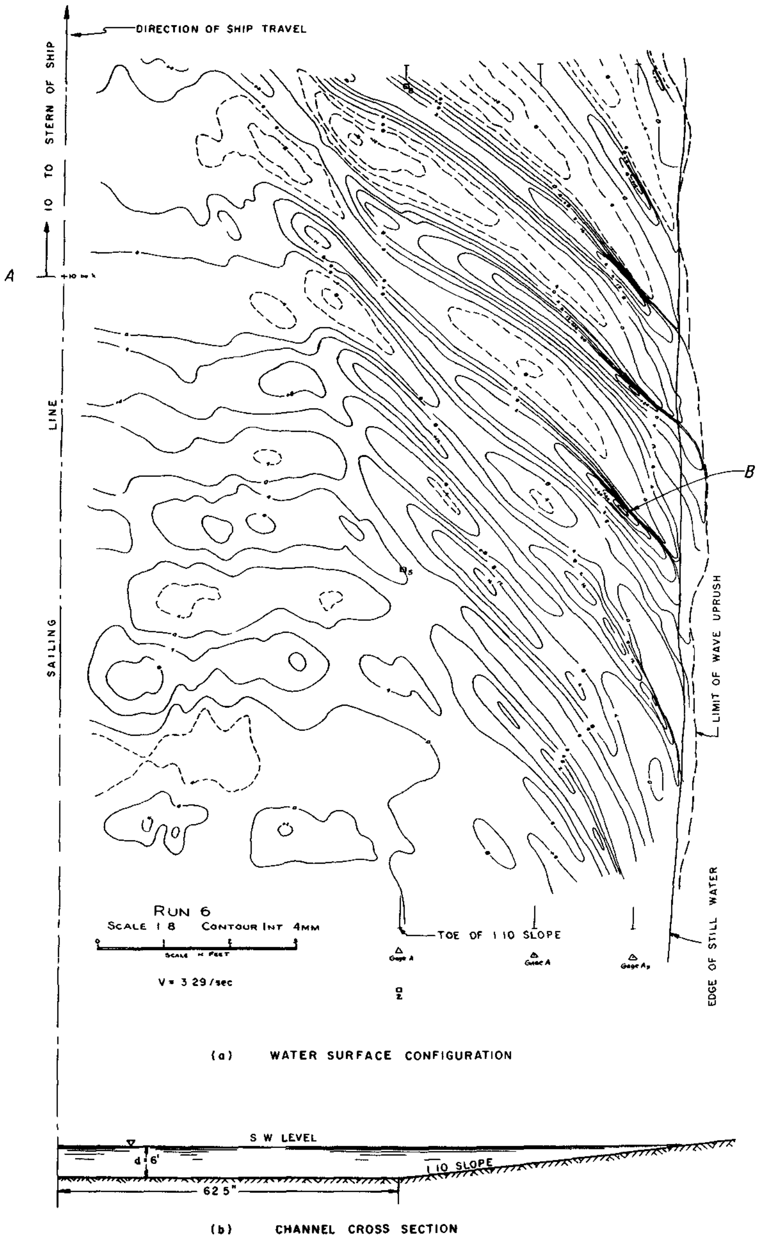

Fig. 4 - Surface contours of waves generated by a Mariner Class cargo ship moving at 19 knots in 48 feet of water 890 feet from the shore which has a 1:10 beach slope.

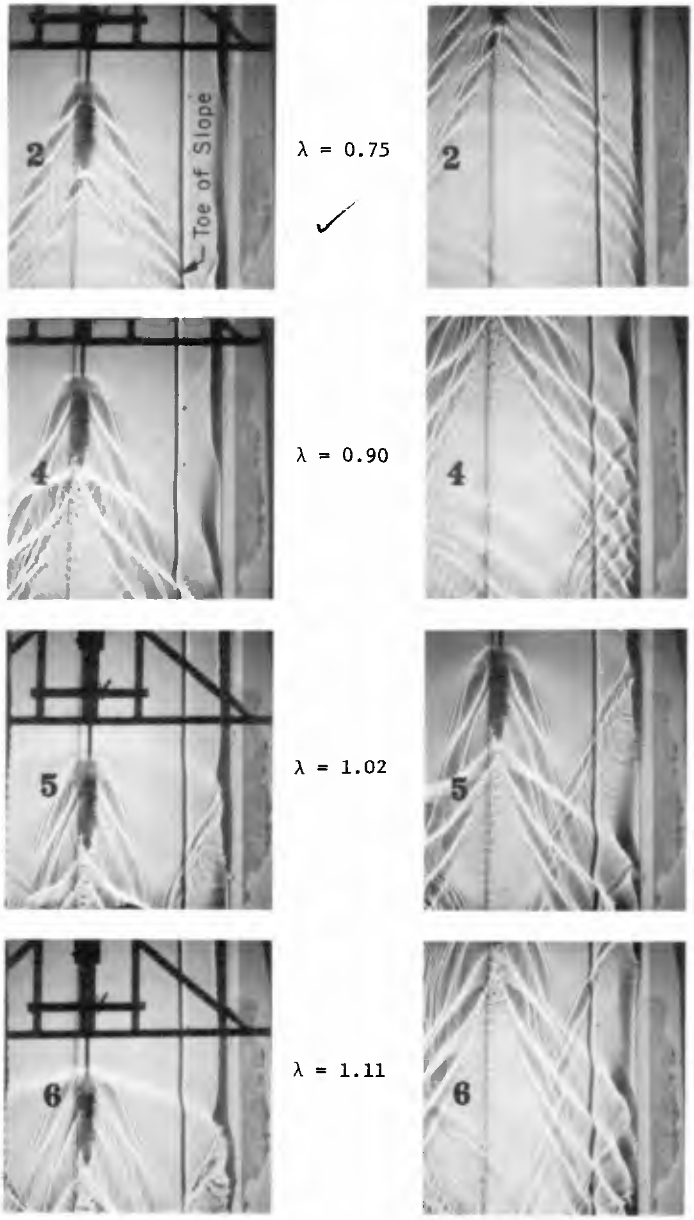

Fig. 5. Ripple tank photographs of ship waves moving onto a beach with a 1:5 slope.

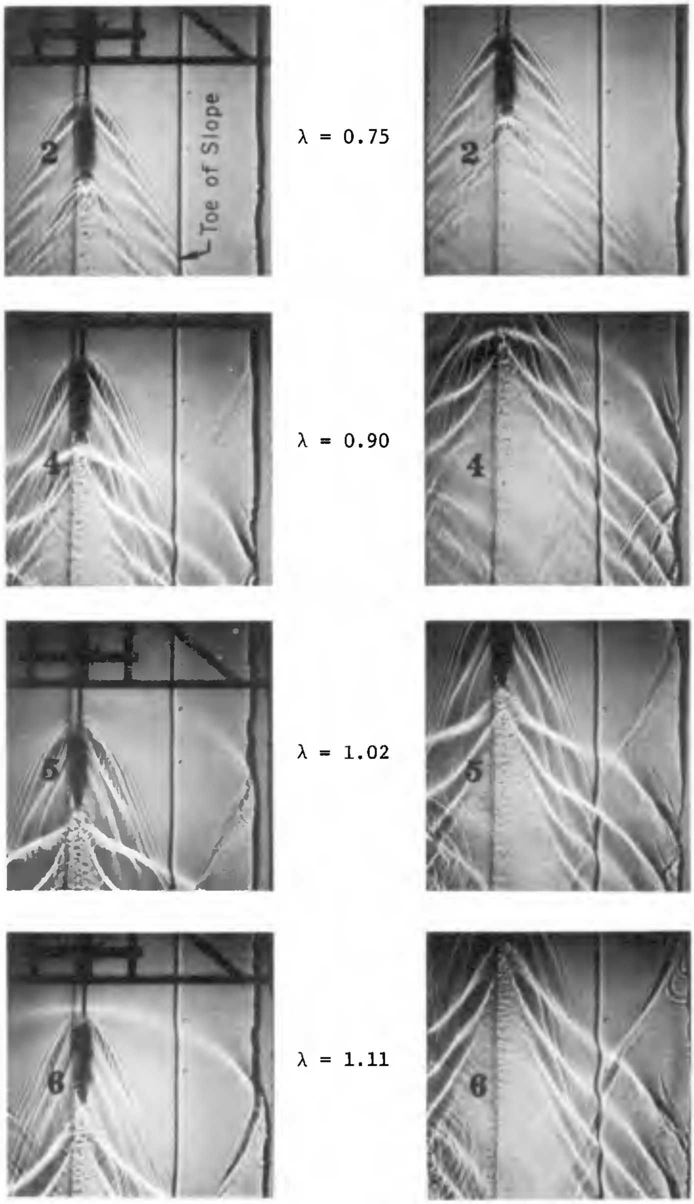

Fig. 6. Ripple tank photographs of ship waves moving onto a beach with a 1:10 slope.