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INVESTIGATION OF SYSTEMS FOR PRODUCING A STANDING WAVE IN A RECTANGULAR TEST TANK

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
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INVESTIGATION OF SYSTEMS FOR PRODUCING A STANDING WAVE IN A RECTANGULAR TEST TANK

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INVESTIGATION OF SYSTEMS FOR PRODUCING A STANDING WAVE IN A RECTANGULAR TEST TANK

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SUMMARY

Investigations were made to study the feasibility of constructing a test tank capable of generating a controllable standing wave with a period of 3.5 to 4.5 seconds. This tank would simulate actual open-ocean conditions for conducting tests to determine the operational readiness of manned spacecraft. Model test tanks scaled to represent a proposed full-scale tank 70 feet in length were used in the investigations. The 70-foot length was chosen to yield the desired tank periods. The variable parameters were tank length, water depth, paddle size and location, and paddle movement. The only method considered for exciting a standing wave in a tank was a paddle system located in the bottom of the tank.

All paddle configurations tested produced a standing wave in the tank; however, some configurations permitted easier control than others. The larger paddles allowed greater latitude in control of wave motion and produced higher waves; but when operating the system at the natural frequency of the tank, the large paddles generated waves which became unstable. This instability was reduced by running the system slightly below the tank's natural frequency, although this procedure produced a smaller wave.

The waves generated in the tanks corresponded to full-scale waves 1 to 5 feet high with periods ranging from 3.5 to 4.5 seconds. The waves tended to beat (depending on the driving frequency) such that at the tank's natural frequency, the wave height varied approximately 50 percent. It is believed that most of the beating was caused by small speed variations in the driving mechanism causing a loss of synchronization between the paddle's motion and the wave.

INTRODUCTION

In order to insure the operational readiness of a manned spacecraft under development to function properly in the postlanding environment, tests are being conducted to investigate the spacecraft's dynamic response under a broad spectrum of probable postlanding conditions and to establish the reliability of systems provided for location and retrieval purposes. Because of the open-ocean landing mode chosen for all United States' manned space flights to date, and plans for this same landing mode to be used in future flights, it has been necessary to conduct these tests under simulated open-ocean conditions, or by actually taking a spacecraft to sea. Sea tests have been very unpredictable because of weather and handling problems, and tests conducted under simulated conditions with present facilities have required compromises resulting in questionable data. Therefore, an indoor facility which would produce an accurate open-ocean environment for the controlled testing of spacecraft has been proposed. This report concerns only the wave-making portion of such a facility.

It was determined that a standing wave would yield a controlled wave in a confined area having the desired slope and period without requiring the usual wave absorbing systems. Also, to provide as large a test area as possible, it was determined that the wave producing system must be located in the ends or bottom of the tank. With these goals in mind, the first of two model tanks was constructed of wood with a paddle located a short distance above the bottom at the tank's center. This paddle was driven by a 1/15-horsepower motor. The paddle produced satisfactory waves, and several experiments were conducted by varying the length of the tank and depth of the water. The tests indicated that the wave period and height could be controlled with such a system. Following these initial tests, a larger model tank was constructed. This tank provided the capability to investigate various paddle sizes, shapes, strokes, and locations in the tank. The results of the tests are described in this report.

APPARATUS AND PROCEDURE

The model test tanks and typical paddle configurations used in the investigations are shown in figures 1 to 4. The model tanks represent a proposed water test tank installation constructed to scale with the exception of the driving mechanism. The projected full-scale tank is 70 feet long, 35 feet wide, and 25 feet deep. The Model Tank 1 shown in figure 2 is 30 inches long, 21 inches wide, and 15 inches deep. Tank 2 (figs. 3 and 4) is 48 inches long, 28 inches wide, and 20 inches deep.

The tanks were constructed of 1-inch-thick marine plywood with a 1/2-inch-thick plexiglass window mounted on one side of Tank 2. The drive mechanism for the paddles was a 1/15-horsepower ac-dc motor controlled by a variable transformer. This motor was attached to the paddle by a direct linkage as shown in figures 2 and 3. The stroke, or degree of up-and-down movement, of the paddle was adjustable by a cam mounted on the motor shaft. The rotational speed, or period, of the drive system was measured by a direct-reading tachometer held against the motor shaft. The motor, drive system, and paddles were all mounted on a 1/4-inch-thick aluminum fixture which could be removed from the tank for configuration changes and adjustments.

The test procedures used in conjunction with Tank 1 (fig. 2) were simply to drive the paddle at a speed that produced a desirable wave. After it was determined that a wave could be produced, a parameter study was performed by varying the paddle stroke, water depth, and tank length. The paddle was mounted in the center of the tank and 30 inches from the bottom (full-scale).

Tank 2 (figs. 3 and 4) was constructed to extend the data of the first tank. Different paddles were tested and their distances from the bottom of the tank were varied, with one series of tests having the paddle located under a wave nodal point. Also, tests were made to determine the wave's sensitivity to paddle speed changes.

RESULTS AND DISCUSSION

All test results are shown full scale and are presented as plotted data in figures 5 to 8. The test results compare favorably with theoretical analyses based on harmonic motion. The simplified mathematical solution for the natural frequency of a water-filled rectangular tank is as follows

$$n^2 = \frac{g}{2\pi L} \tan h \frac{2\pi d}{L}$$

where: n = natural frequency

g = gravity coefficient

L = tank length

d = water depth

Solving this equation for the 70-foot tank tested (figs. 5 and 6) yields a tank natural frequency of 3.75 seconds, which agrees closely with the maximum wave height in most of the plots in figure 7. Figures 5 and 6 show the effect of tank length and water depth on the period and wave height. Also shown is a curve representing the theoretical values for tank depth versus period.

Figures 7 and 8 show plots of wave height versus period, which gives an indication of the relative sensitivity of a paddle system's period with respect to the resultant wave. The initial tests performed in Tank 1 (shown in fig. 2) indicate that a change in water depth has very little effect on the wave height, although it might be expected that a further decrease in water depth would cause a more definite result, since the paddle would be closer to the surface.

The effect of paddle stroke on wave height was quite noticeable and seems to be an effective method of wave amplitude control. However, the large paddle movements may cause undesirable eddies on the surface of the water. These eddies and crosscurrents were noticed in some tests, although they did not appear to interfere with the standing wave. It is believed that the eddies were caused by water being forced between the paddle and tank bottom. Also, when the paddle was relatively near the surface, there were cases in which irregular motions were superimposed on the standing wave.

Wave periods seemed readily controlled by varying the depth of the water or by changing the length of the tank. The tank's length was varied by inserting blocks in both ends; however, this may be accomplished with movable baffles in a full-scale tank.

To determine the sensitivity required for the control system in a test tank of the dimensions described in this report, refer to the plots in figure 7. These plots show the wave height changes as a function of period or paddle speed. Generally, a very slight change in paddle speed in the area of the tank's natural frequency results in a large increase or decrease in wave height. This is a normal property to be expected in this type of resonant system and cannot be appreciably altered. Therefore, an effective control system must have the capability of controlling the paddle speed within approximately 1 part in 200, depending on the paddle system used. The largest paddle tested allowed the widest range of control. However, at the tank's natural frequency where the largest waves are produced, the control of all paddles would have to be extremely fine in order to avoid instability or severe beating.

The plots in figure 8 show the effect of moving a centrally-located paddle vertically in the tank. These tests were made to determine the effects of placing a paddle at different distances above the bottom of the tank. The lowest position, 1.46 feet, caused an excessive amount of waterflow in the bottom of the tank, resulting in poor wave-making characteristics; however, the paddle mountings from 2.92 feet to 5.84 feet produced good waves with satisfactory control. The highest position, 7.30 feet, caused surface roughness and eddies; however, the standing wave was not significantly altered.

During all paddle tests, except for the very short stroke runs, wave instability and severe beating occurred when the system was operating at the tank's natural frequency and the waves were at their maximum height. It is believed that most of this instability was caused by slight variations in paddle speed. It was noted that the paddle motion would become out of phase with the wave motion just prior to the start of instability; however, the system would return to a stable wave within several minutes.

CONCLUSIONS

Results of the model water tank investigations indicate that it is feasible to generate standing waves of 1 to 5 feet in height in a 70-foot-long tank, and that these waves can be controlled by varying the paddle stroke and drive system speed.

The paddle system may be mounted in the center of the tank or at either of the nodal points of the standing wave. A distance of 3 to 5 feet from the tank's bottom seems to be the best vertical position for a paddle. With regard to paddle size, a 12-foot-wide paddle extending the width of the tank appears to be the best configuration tested.

In order to maintain satisfactory control of the standing wave tank, it will be necessary to have a system capable of regulating the paddle speed and matching the wave motion to the paddle's position. Such a system might be a wave height sensor coupled with a speed control accurate to at least 1 part in 200. Also, for wave height adjustment, a paddle stroke controlling system may be built into the tank, although paddle speed control might serve this function. Furthermore, if wave period control is desired, provision for changing the water level or tank length must be made.

The problems of wave instability and beating were not resolved in this investigation; however, this condition exists only at large wave amplitudes, and it may be possible to use the beating properties to simulate the actual wave trains found in the open ocean. Although instability may be a problem with a large standing wave, it is thought that a good control system will alleviate most of the condition.

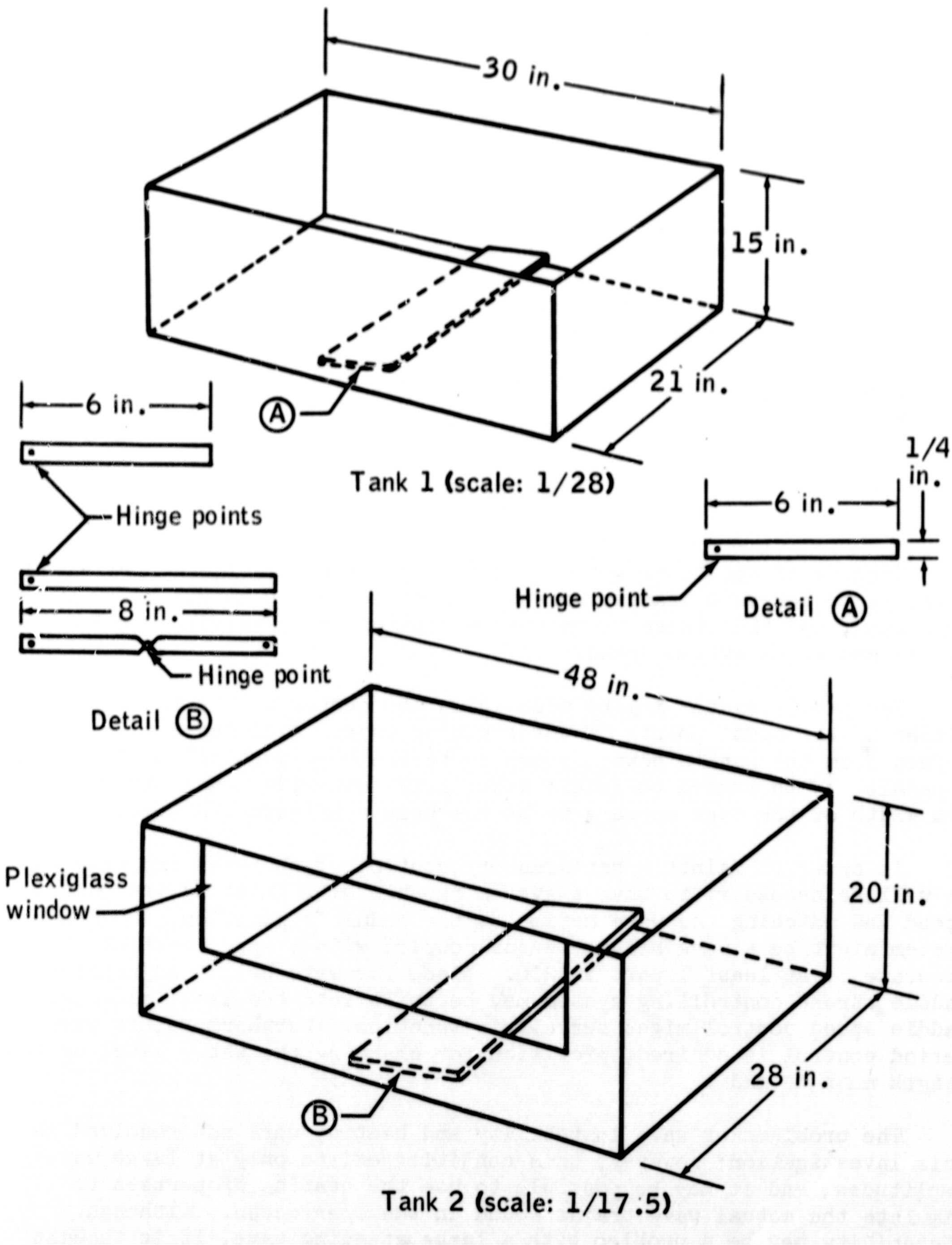

Figure 1.- Test tank dimensions and paddle sizes.

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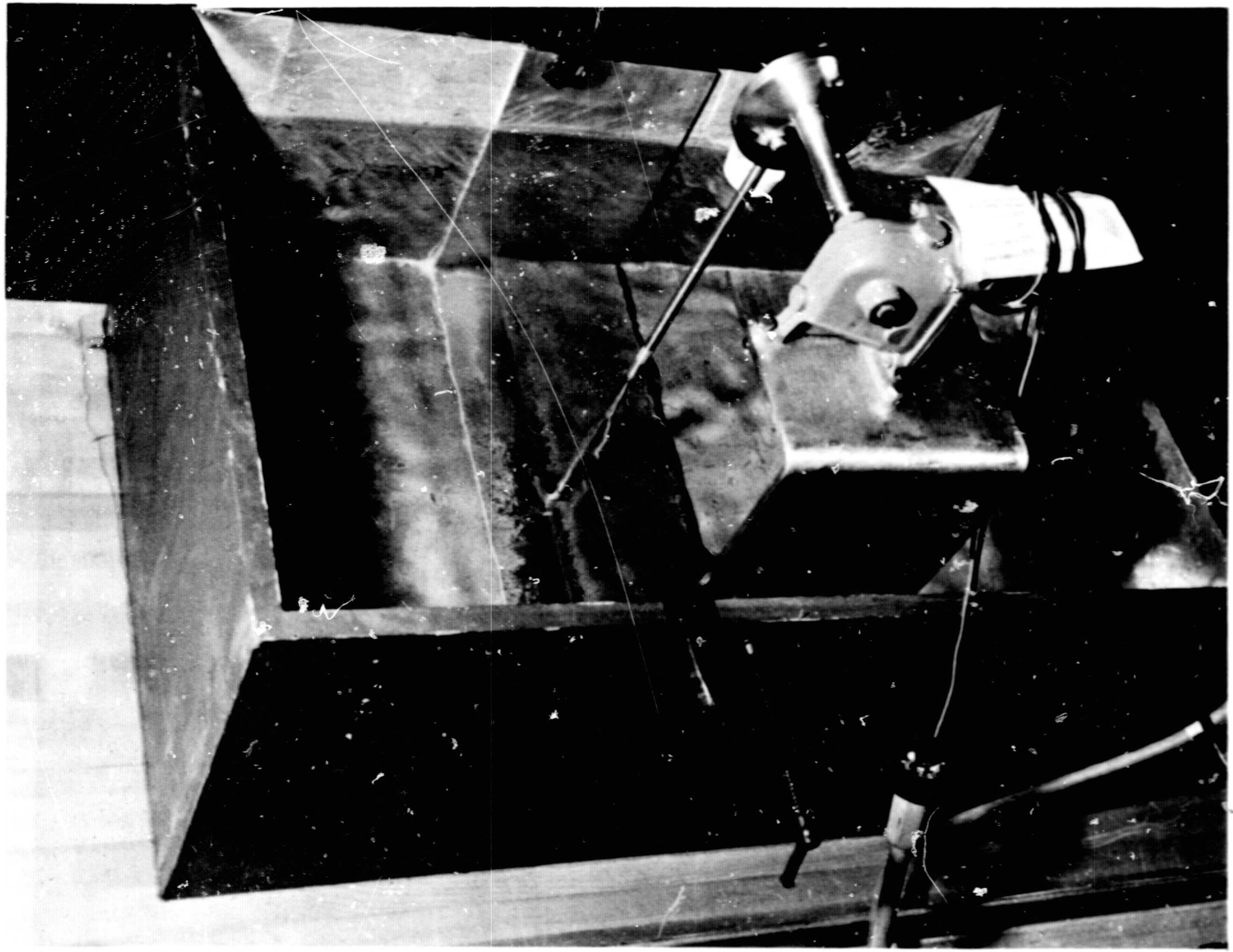

Figure 2.- Tank 1 showing paddle location and driving mechanism.

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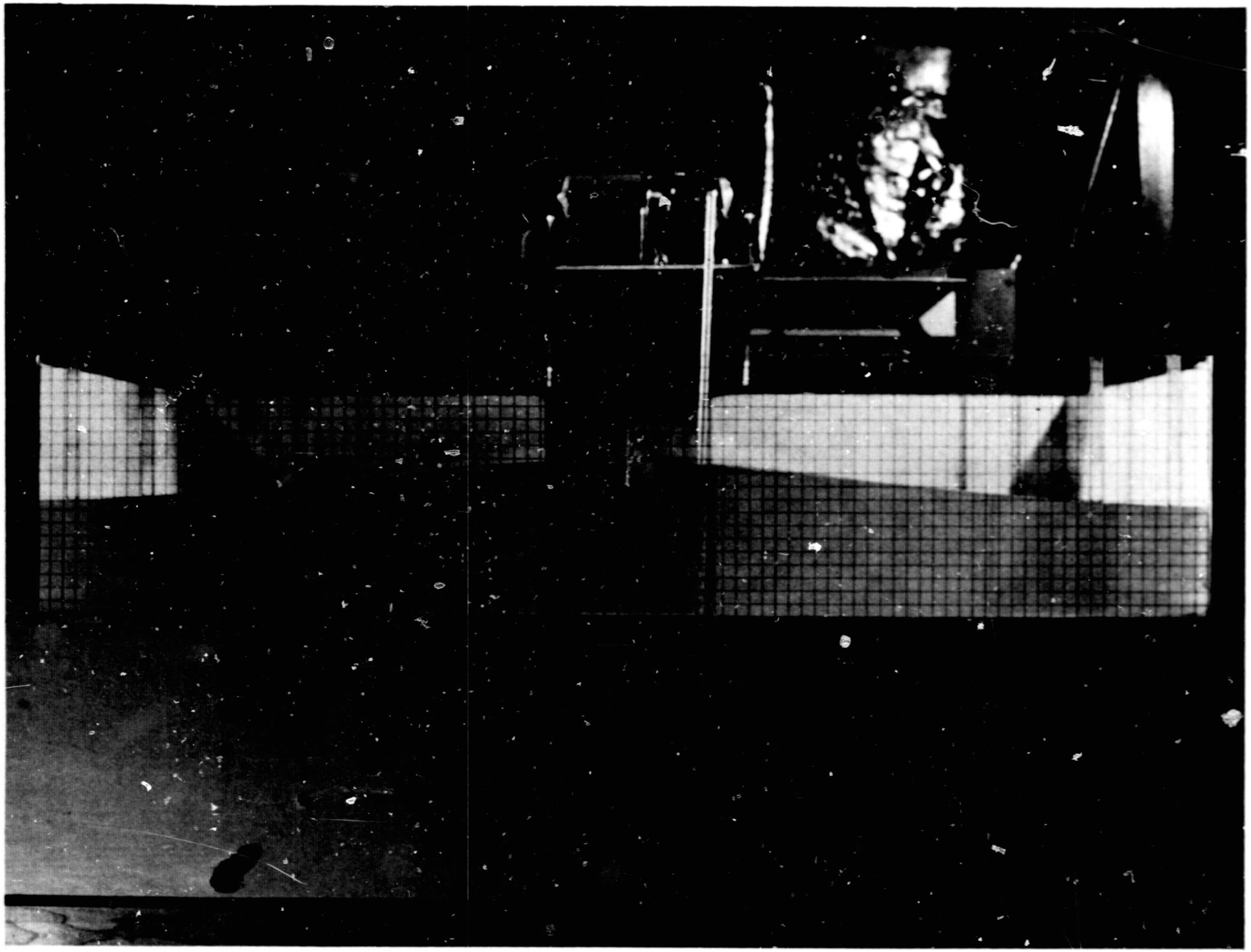

Figure 3.- Tank 2 with a standing wave being generated.

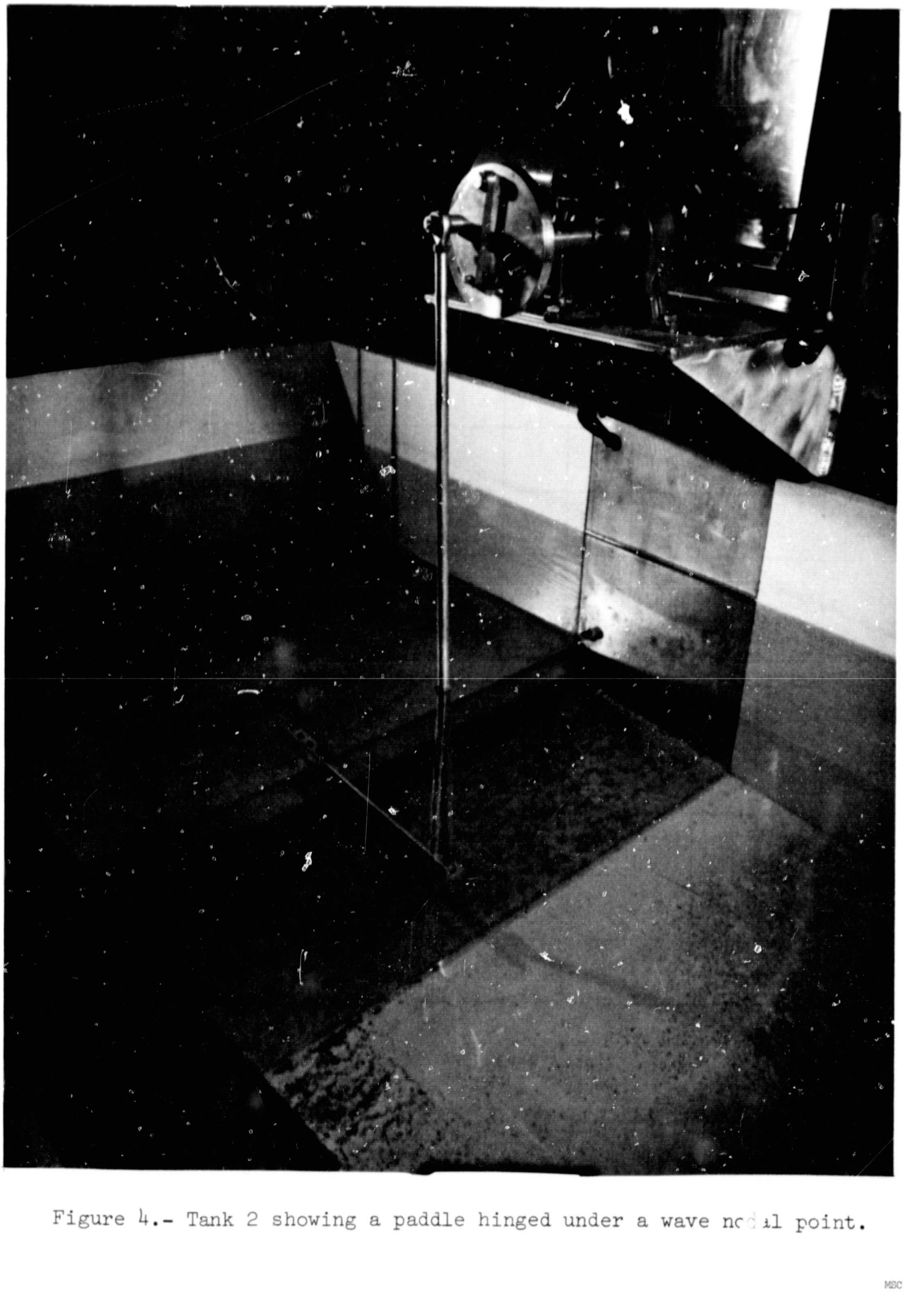

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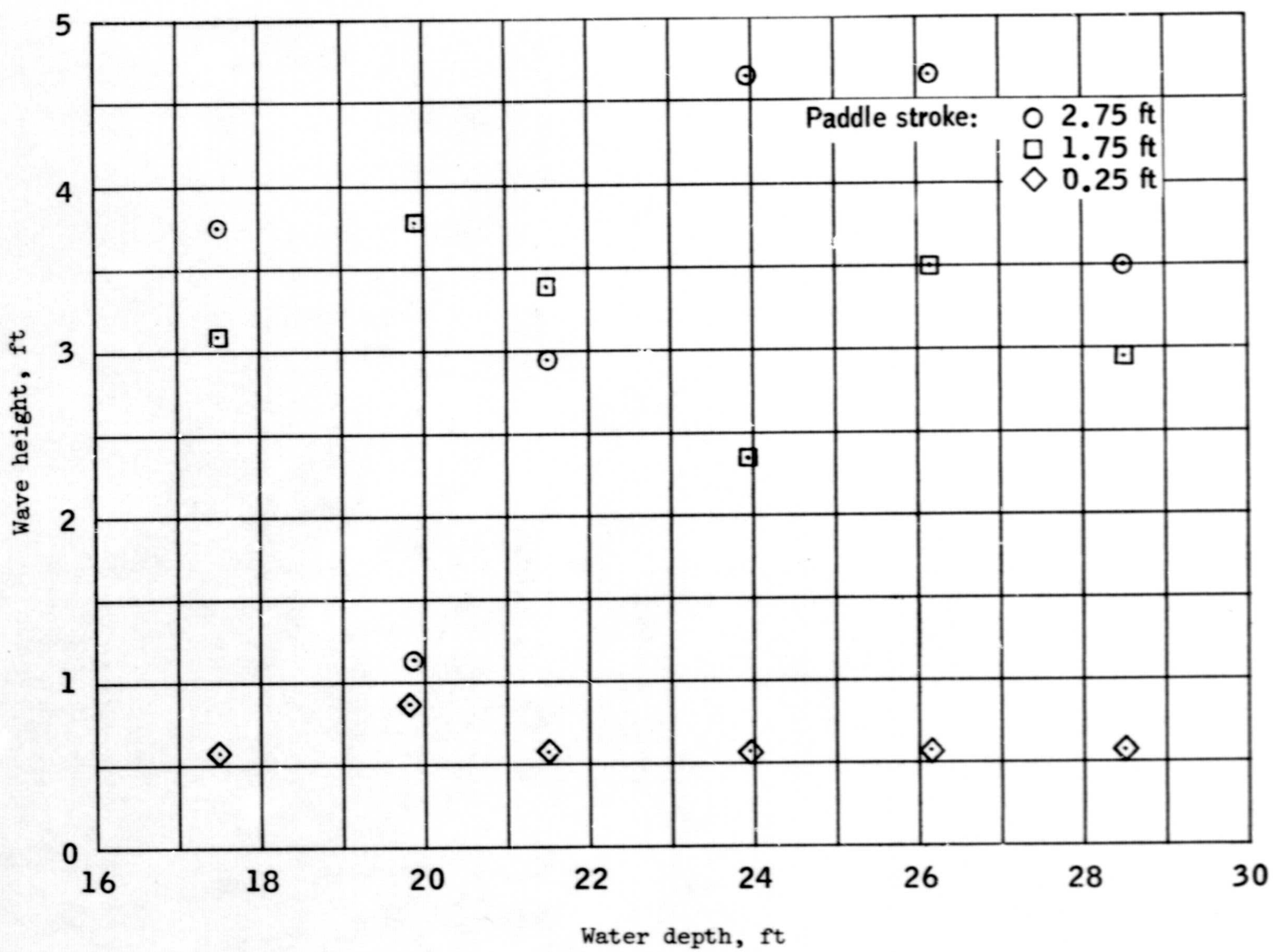
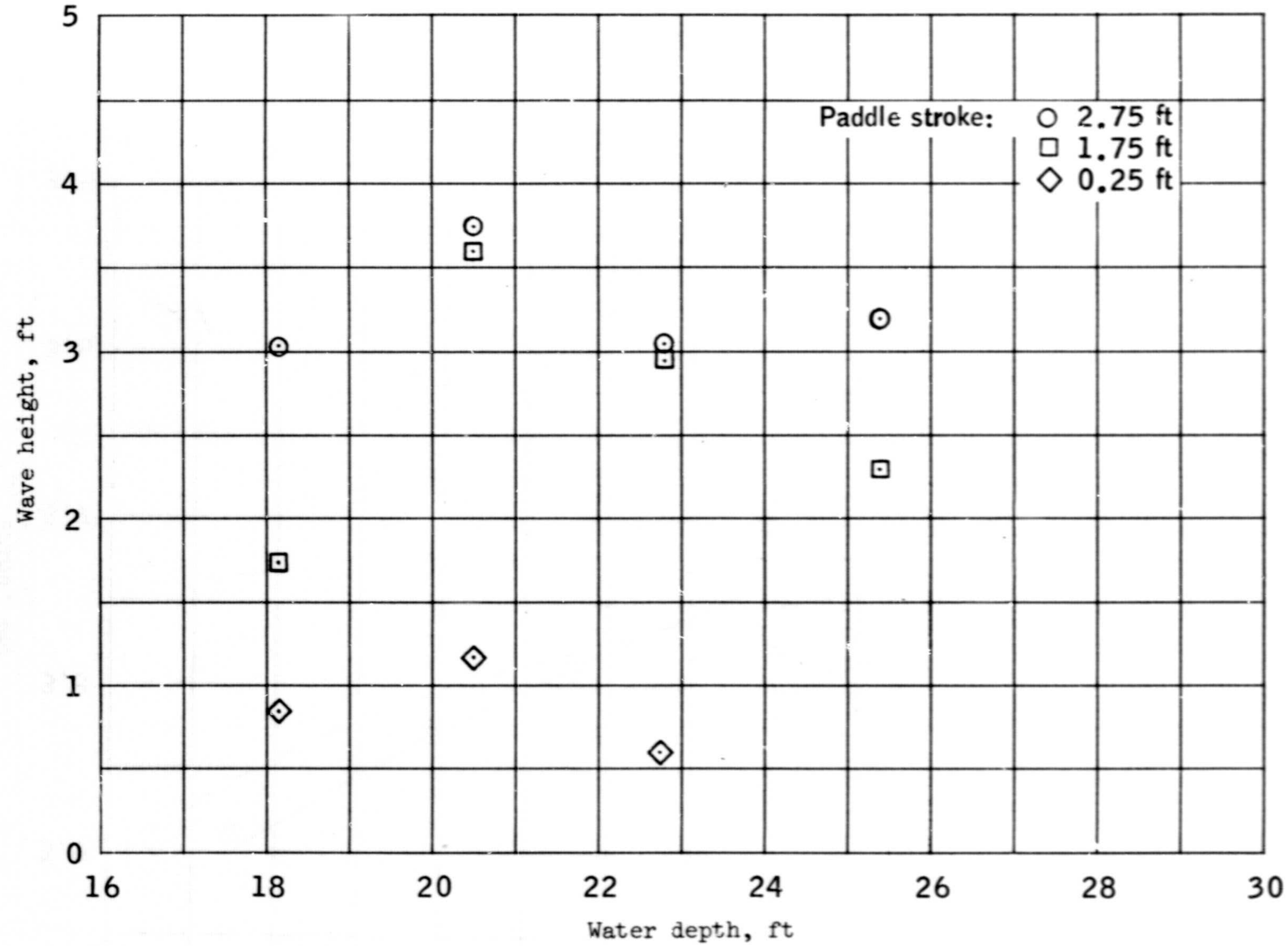
Figure 4.- Tank 2 showing a paddle hinged under a wave nodal point.



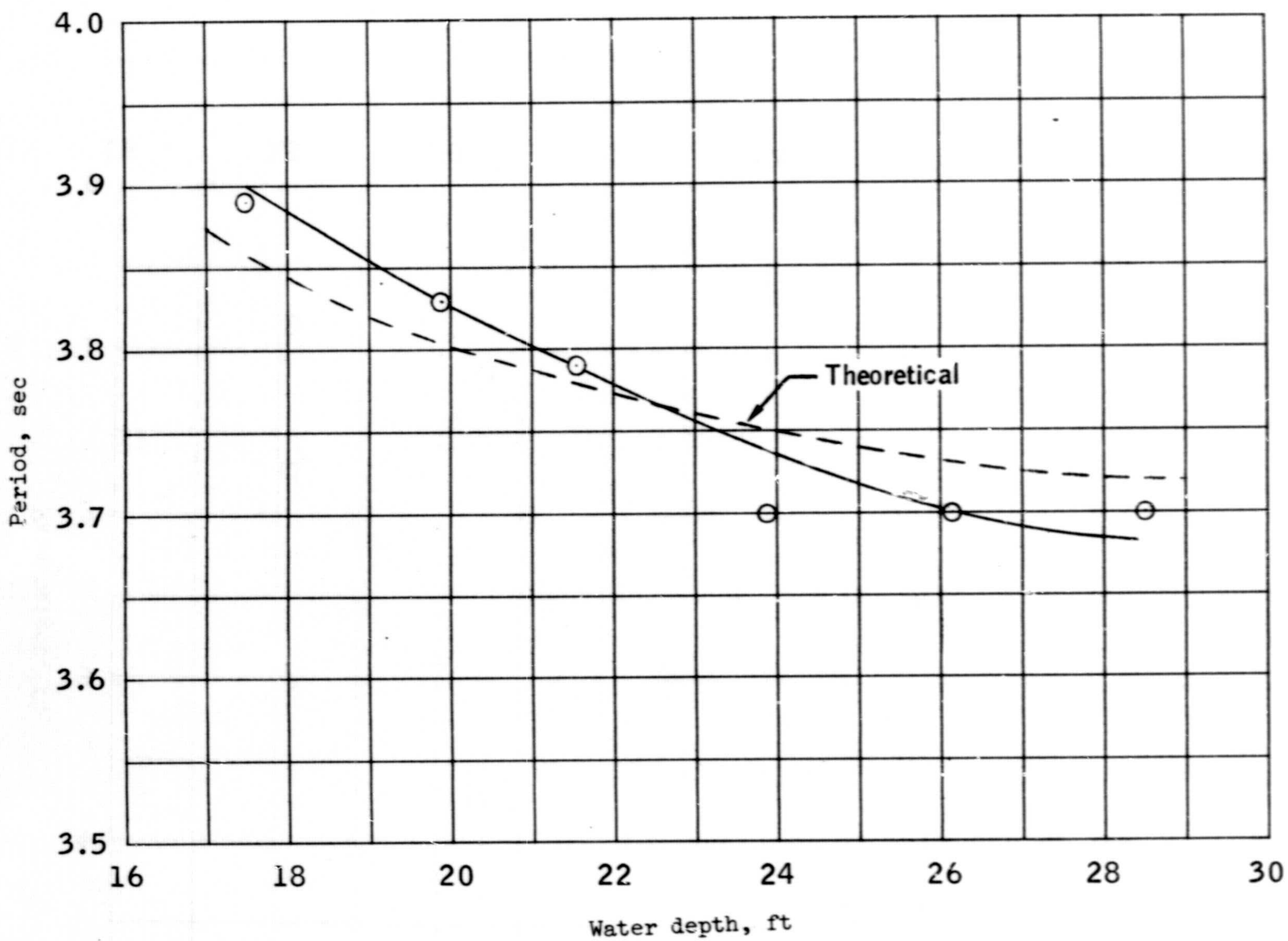
(a) Tank length — 70 feet.

Figure 5.- Effect of tank length and water depth on maximum wave height (Tank 1).



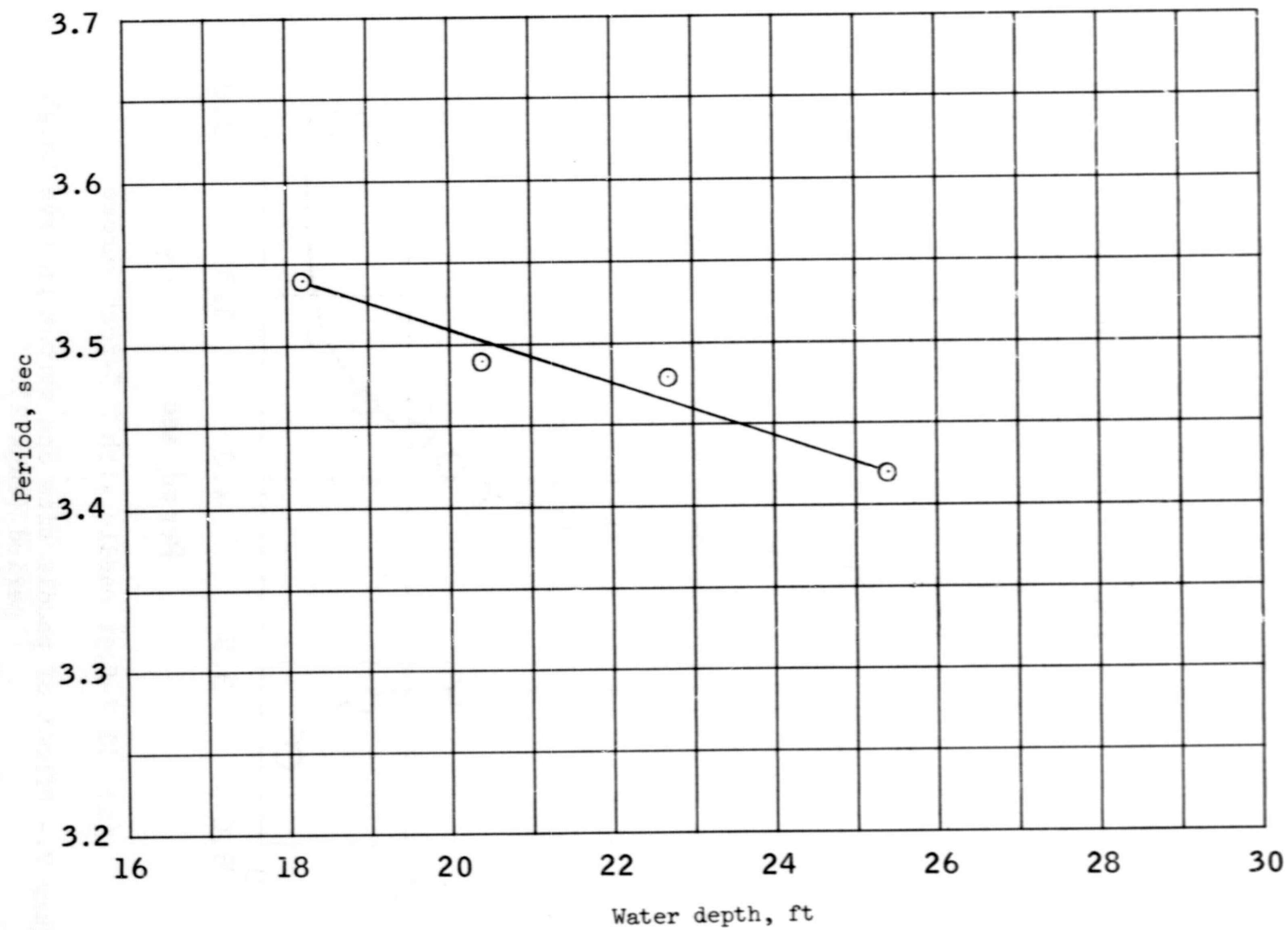
(b) Tank length — 61 feet.

Figure 5.- Concluded.



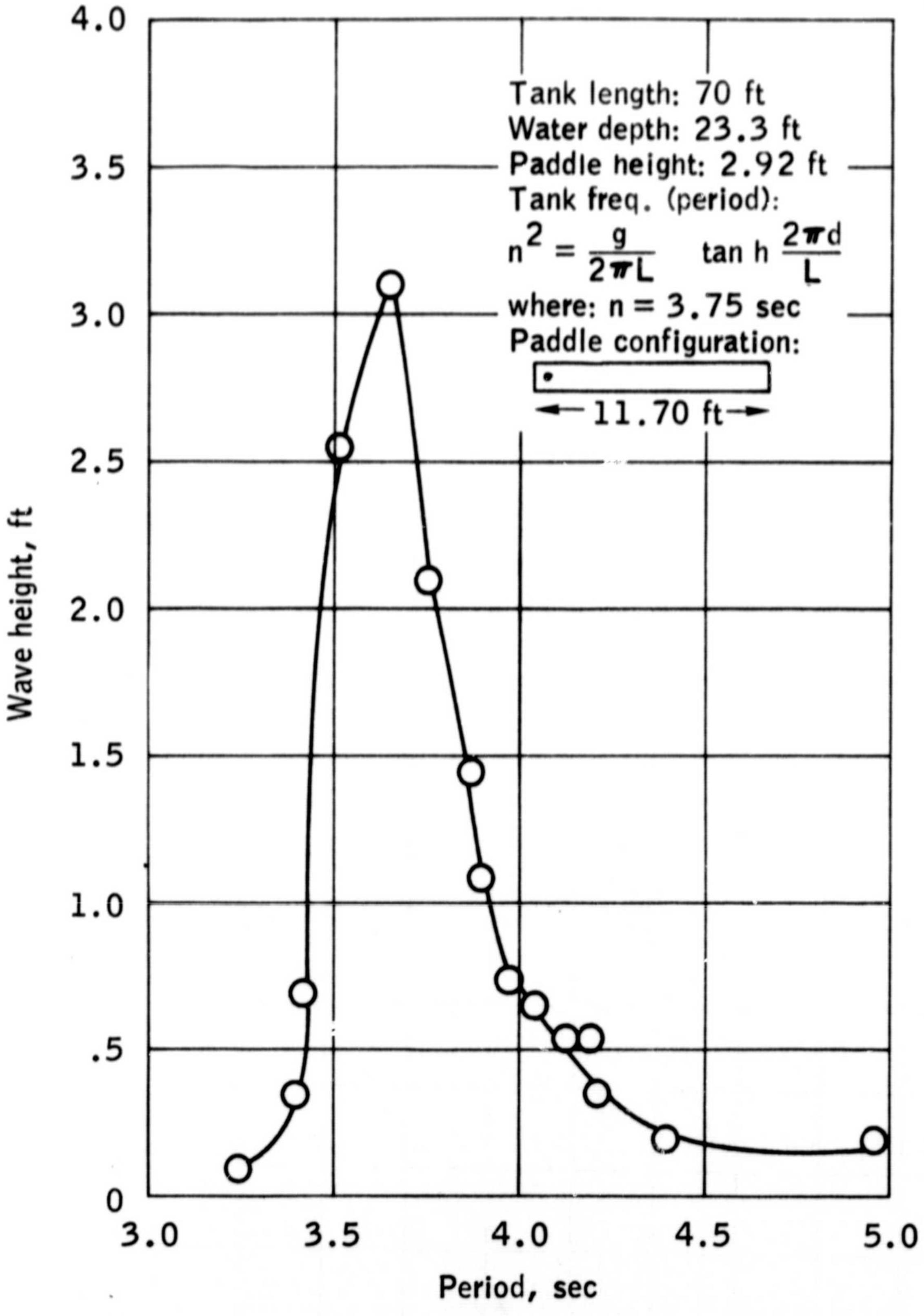
(a) Tank length — 70 feet.

Figure 6.- Effect of tank length and water depth on wave period (Tank 1).



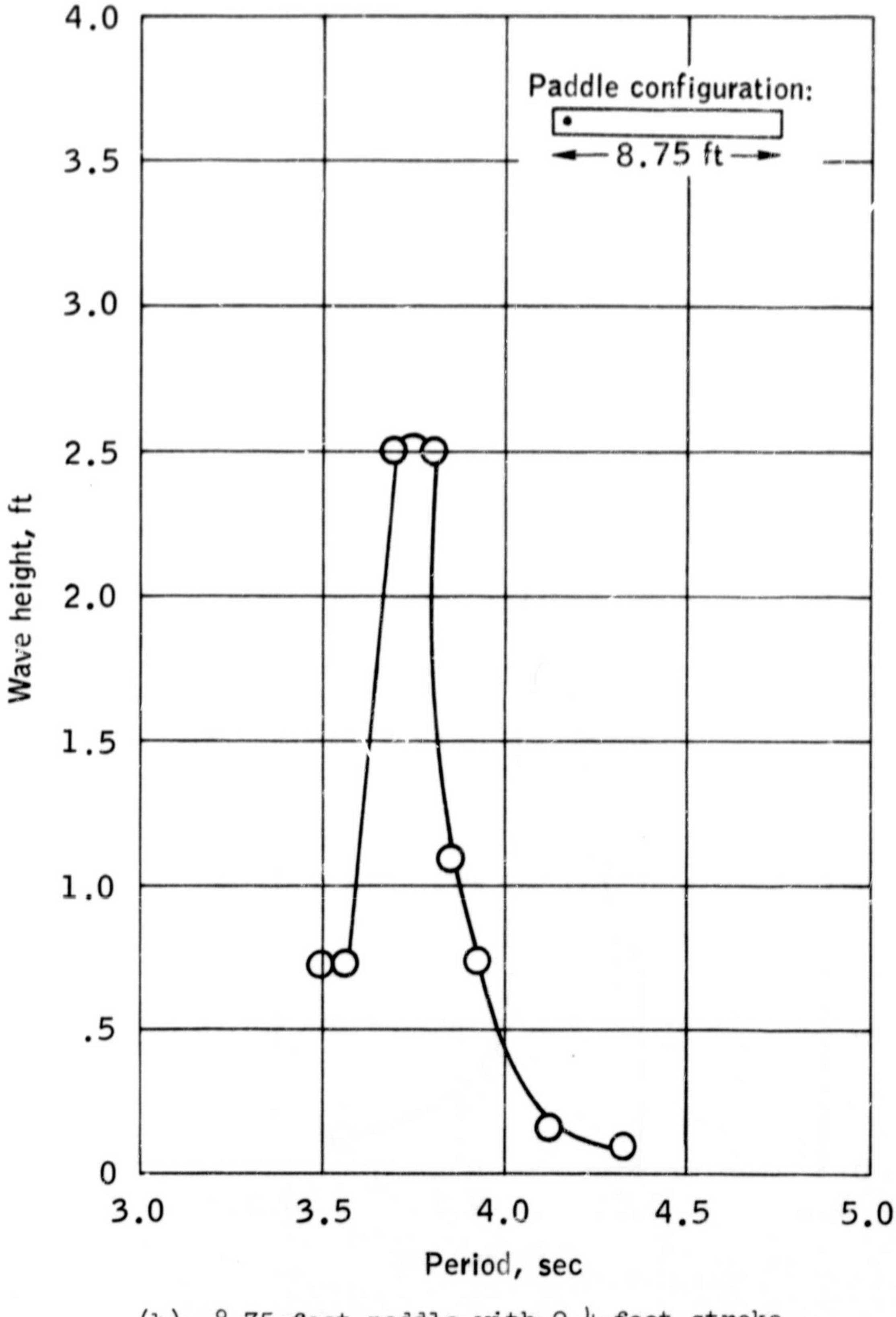
(b) Tank length — 61 feet.

Figure 6.- Concluded.



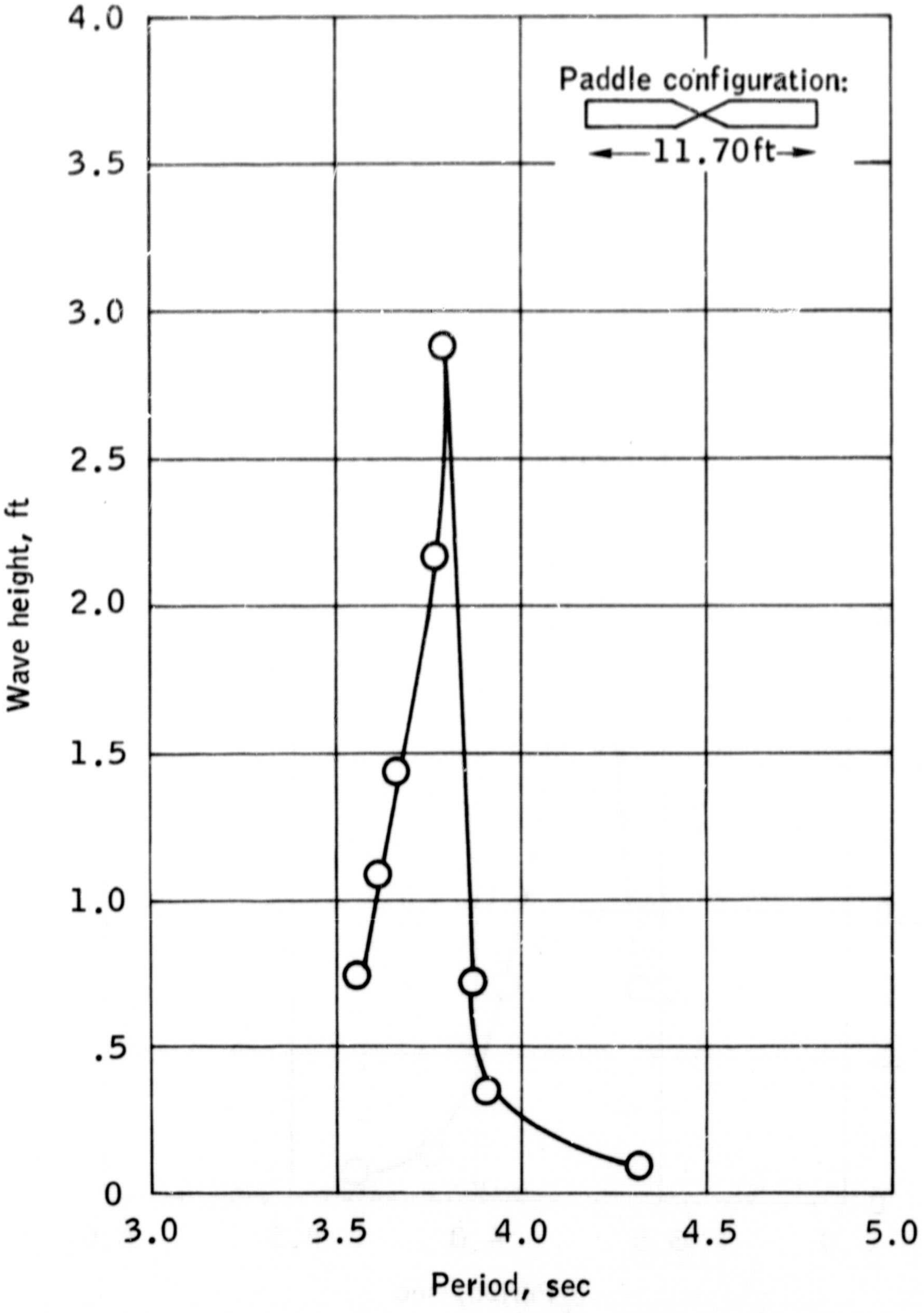
(a) 11.7-foot paddle with 2.5-foot stroke.

Figure 7.- Effect of paddle size and stroke on wave height and period (Tank 2).



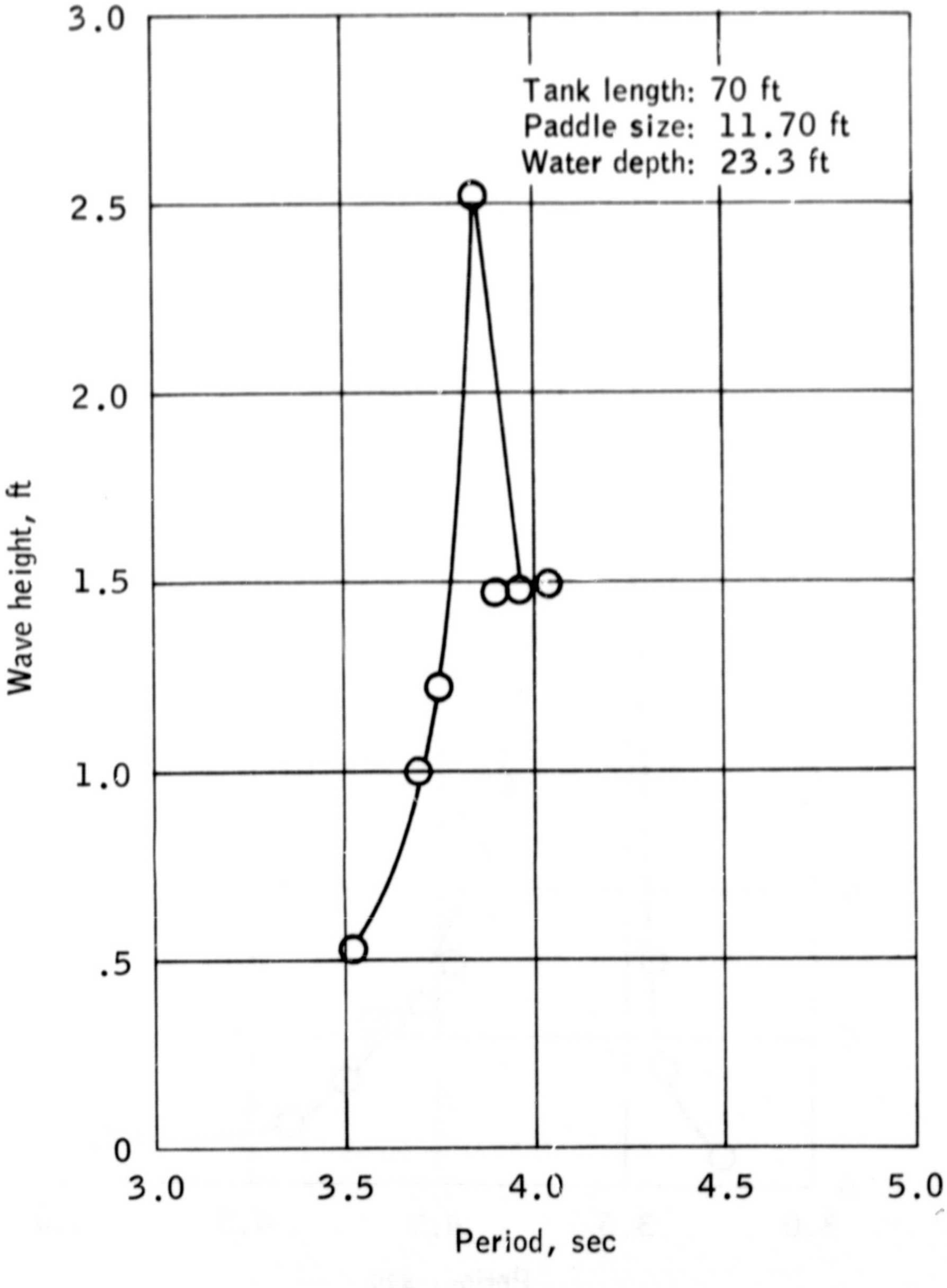
(b) 8.75-foot paddle with 2.4-foot stroke.

Figure 7.- Continued.



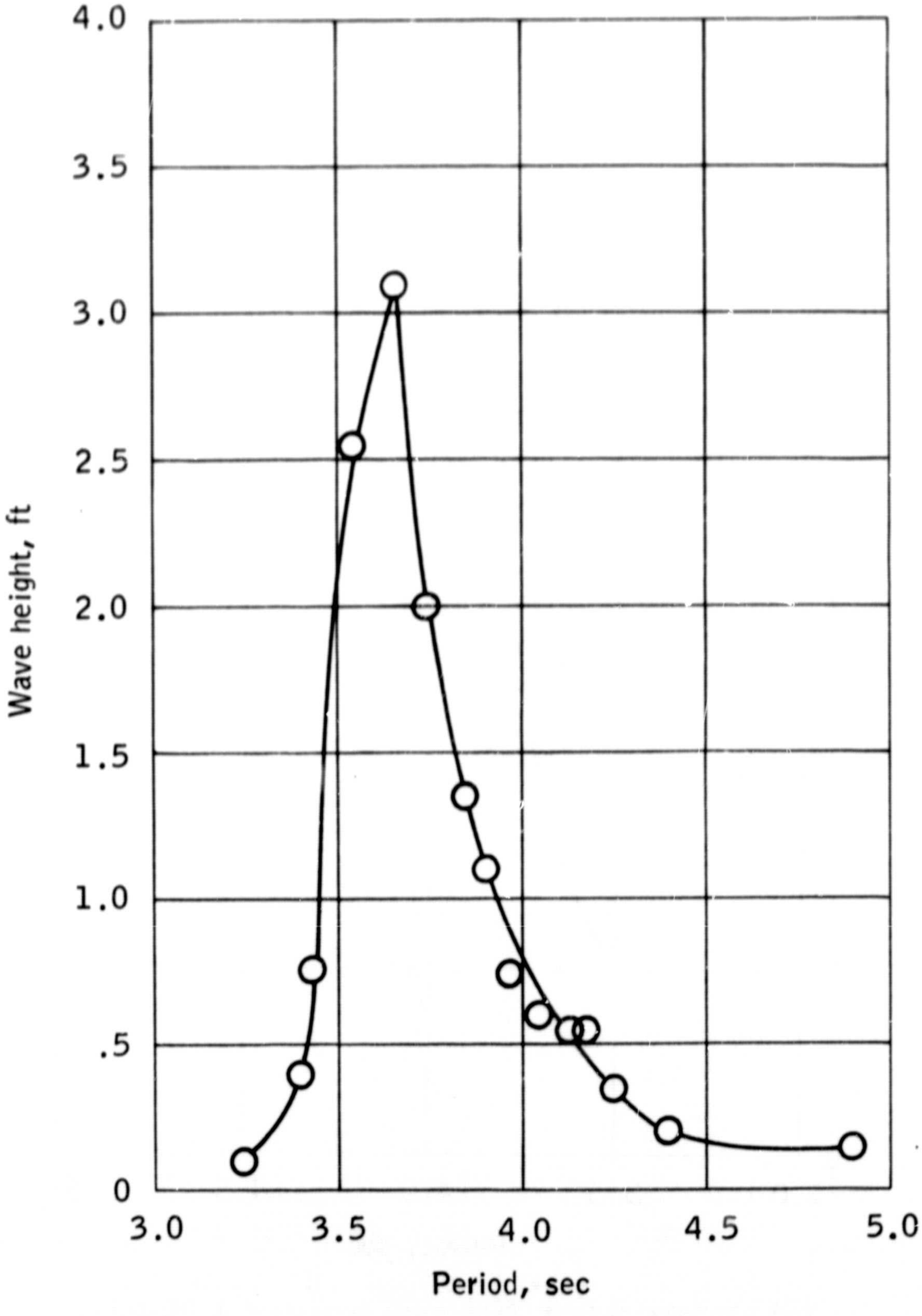
(c) 11.7-foot paddle with 1.8-foot stroke.

Figure 7.- Concluded.



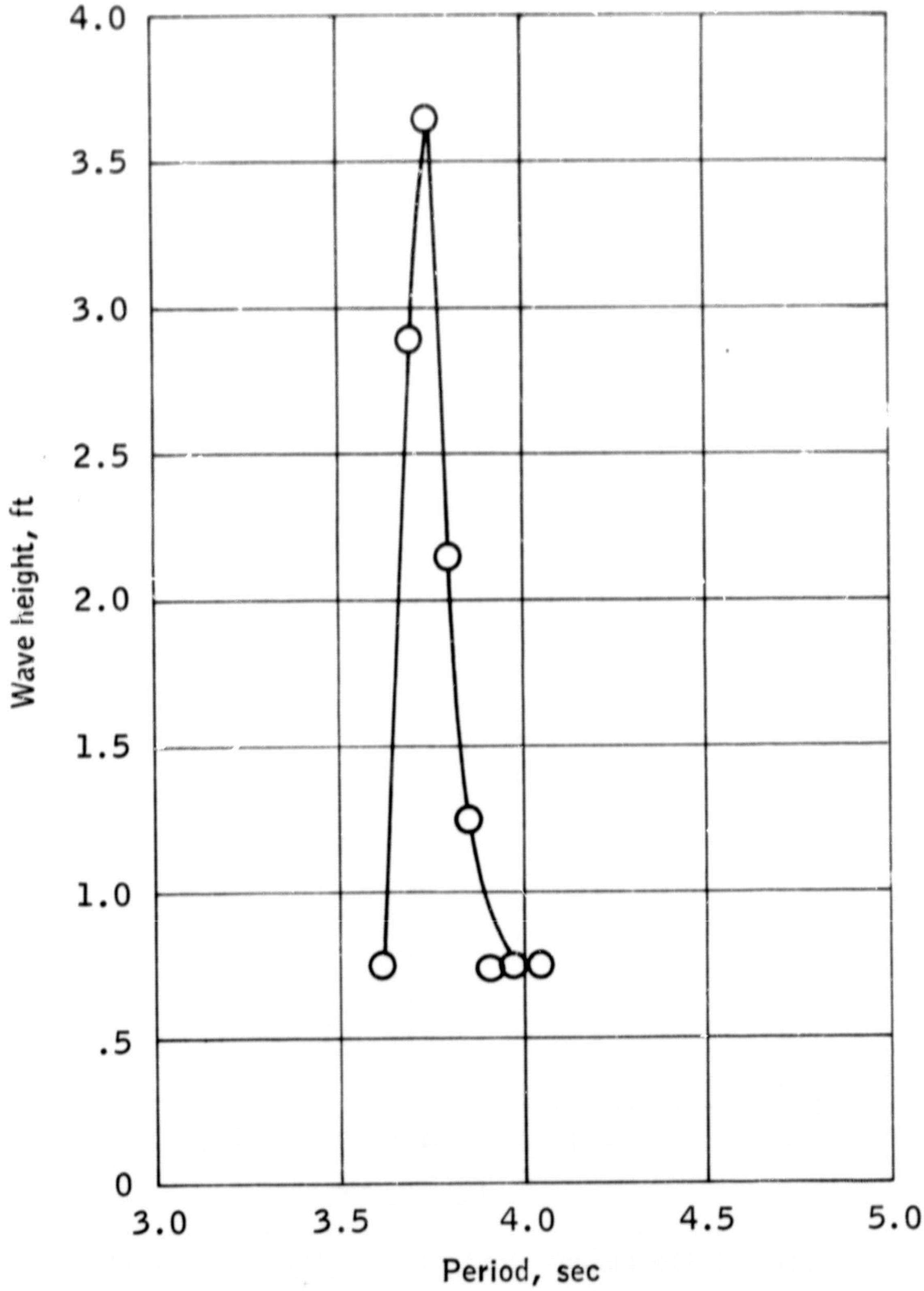
(a) Paddle height from tank bottom = 1.46 feet.

Figure 8.- Effect of paddle height on wave height and period (Tank 2).



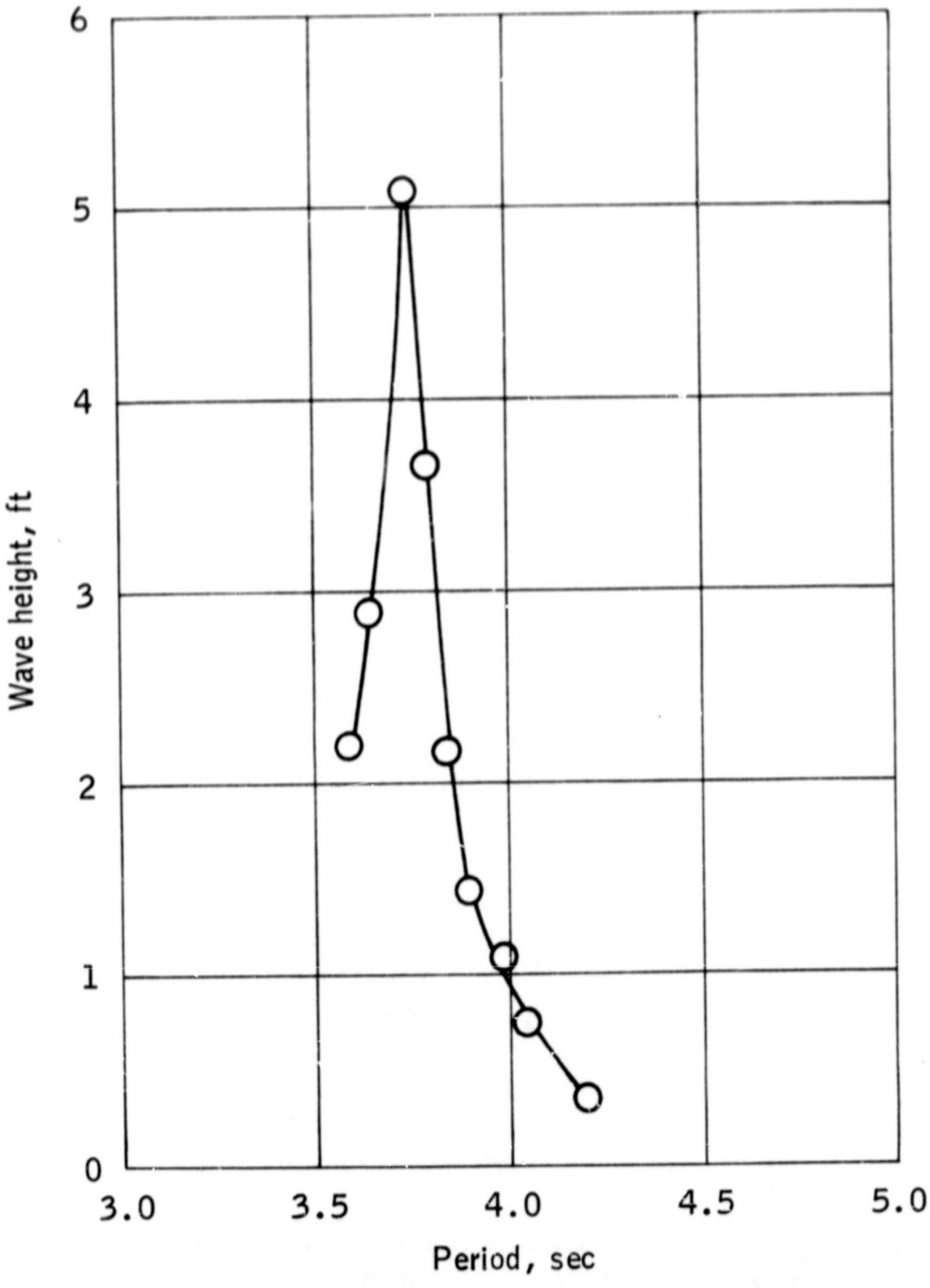
(b) Paddle height from tank bottom = 2.92 feet.

Figure 8.- Continued.



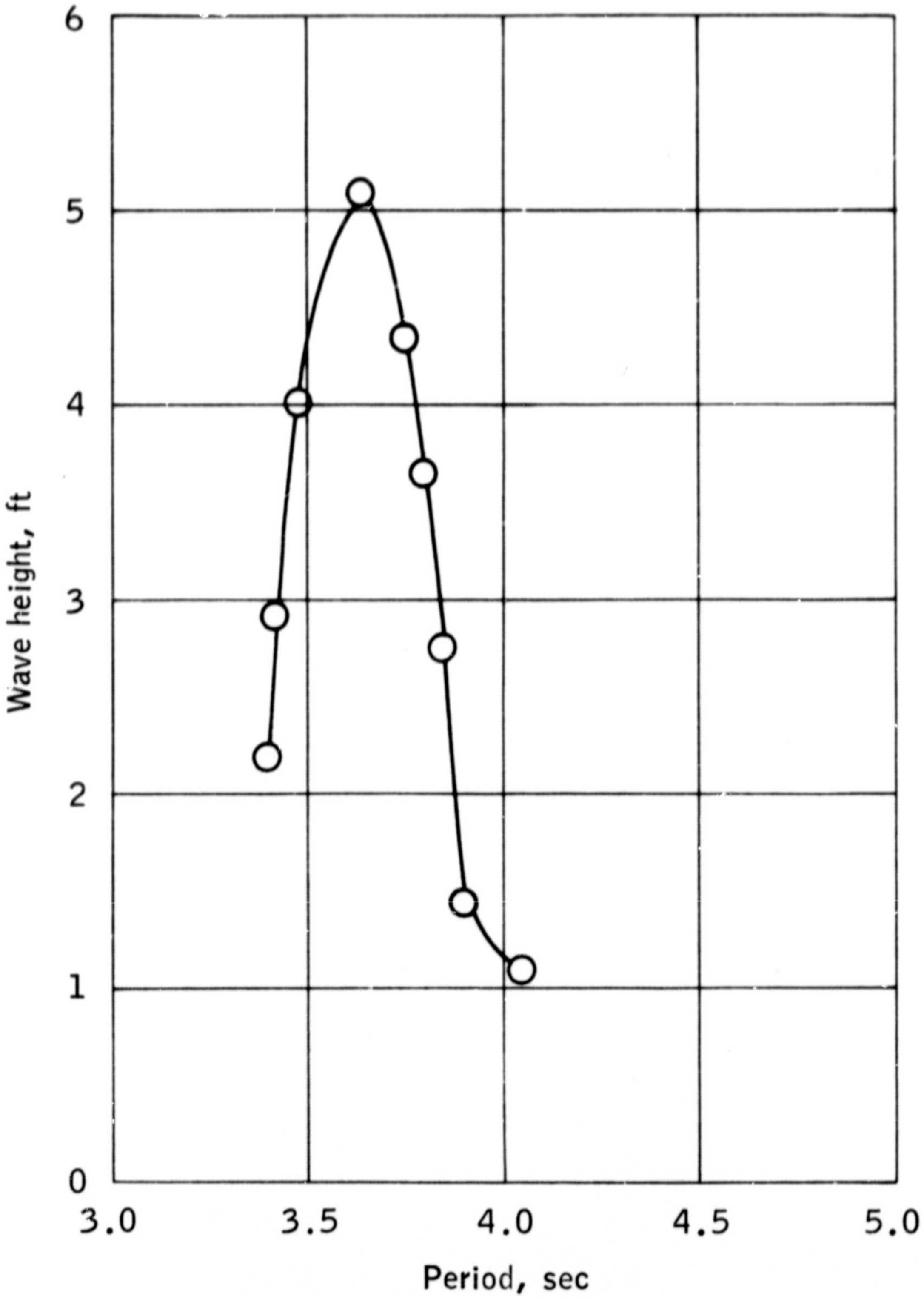
(c) Paddle height from tank bottom = 4.38 feet.

Figure 8.- Continued.



(d) Paddle height from tank bottom = 5.84 feet.

Figure 8.- Continued.



(e) Paddle height from tank bottom = 7.30 feet.

Figure 8.- Concluded.