CHAPTER 63

3-D HYDRAULIC MODEL OF WAVES GENERATED BY DISPLACEMENTS

by

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ABSTRACT

Measurements were made of the water waves generated by the horizontal motion of submerged plungers. The results obtained in a three-dimensional hydraulic model experiment, using a plunger 0.5 ft. wide and 0.25 ft. high, were compared with both the experimental results and theory for the two-dimensional case. It was found that at a given location the ratio of the elevation above the still water level (SWL) of the first wave (the largest wave of the group for the range of variables tested) to the displacement of the plunger (H_3/λ) was found to be dependent upon the Froude Number N_{Favg} (based upon the average plunger speed and the water depth) and upon the ratio of the height of the plunger to the water depth (D/d). For a constant value of θ, H_3/λ increased with increasing N_{Favg} and D/d. A few additional tests were made using a plunger 2.0 ft. wide and 0.25 ft. high. The results show that H_3/λ depends also upon the ratio of water depth to the width of the plunger (d/W).

INTRODUCTION

The generation of waves by a tectonic displacement has been solved for the two-dimensional case by Garcia (1972) using a numerical model (ABMAC, Arbitrary Boundary Marker And Cell). Garcia compared the results from his

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numerical model with those obtained from a hydraulic model study of several types of boundary motions for a fairly large range of Froude numbers and found that the numerical model is quite good. It appears, however, that the largest existing digital computer in the U.S. does not have the capability to permit the use of ABMAC to solve three-dimensional problems of this type, except for the case of radial symmetry. The two-dimensional case is useful as an approximation to some prototype cases. For other cases it is not. Owing to this it was decided to test the applicability of the two-dimensional numerical results in three-dimensional cases, making use of a hydraulic model.

LABORATORY ARRANGEMENTS AND PROCEDURES

The experimental arrangements are shown in Fig. 1. The experiments were conducted in a tank which was 5.5 feet wide by 16 feet long by a little less than 3 feet deep. "Steps" were placed along one side wall of the tank. They were 0.50 ft. and 2.00 ft. wide, with both of them being 0.25 ft. high, containing a movable plunger. The design and operation of the mechanism used to cause the plungers in the steps to move horizontally has been described by Garcia (1972) and by Das and Wiegel (1972).

A rotating boom was constructed which pivoted about a pin connection which was located at the centerline of the step, above the front end of the plunger. Parallel wire resistance wave gages (Wiegel, 1953) were mounted on the boom to sense the disturbance of the water surface. A transducer to measure the displacement of the plunger was installed between the tank frame and the moving arm (Fig. 1). The outputs of the wave gages and the plunger displacement transducer were amplified and recorded on an 8-channel strip chart recorder. A number of tests were made to check the reproducibility of results, which was found to be excellent.

Falling weights were used to drive the plunger, with the total plunger displacement (λ) occurring during a time interval τ.

Wave-absorbing material was placed along the three sides of the tank to minimize reflections.

TWO-DIMENSIONAL TESTS

A series of tests were made to be certain that the new arrangements were such that Garcia's (1972) hydraulic model studies could be reproduced. To do this a vertical training wall was placed alongside the W = 0.50 ft. wide step, extending the entire length of the tank. Thus, a two-dimensional channel was formed, as in Garcia's tests. A typical example of a water surface profile is shown in Fig. 2. The agreement between measurements and predictions made using the numerical model of Garcia was found to be very good.

THREE-DIMENSIONAL TESTS

The training wall described in the previous section was removed, and the waves were permitted to radiate in an entire half plane. The ratio of the first wave crest elevation above the SWL (measured along the wall) to the equivalent measurement for the two-dimension case (H_3/H_2), as a function of the normalized distance from the plunger (x/d) is shown in Fig. 3. In this figure, λ is the total displacement of the plunger, W is the width of the plunger, τ is the time required for the displacement to occur, N_{Favg} is the Froude number ($V_{avg}/\sqrt{gd}$), V_{avg} is the average speed of the plunger movement (λ/τ), g is the acceleration of gravity and d is the water depth in the tank. For the range of conditions tested (three values of Froude number, N_{Favg}), the first wave was the highest wave. It is evident for a source of the type tested, that H_3 is much smaller than H_2, except near the source. The averages of the data shown in Fig. 4 have been plotted on logarithmic paper in Fig. 4. It can be seen that H_3/H_2 decreases as $(x/d)^{-3/5}$ for values for $x/d > 0.7$. For x/d greater than about 6, H_3/H_2 is less than 0.2.

Some data on the surface spread of the waves are given in Fig. 5. Data for two of these cases were plotted in Fig. 6. The elevations of the first crest above SWL were measured at a radius of 0.50 ft. for $0 \leq \theta \leq 90$ degrees. These values of H_3 were plotted versus $r \sin \theta$, and it was found that there was a nearly linear relationship between the two variables. In these tests $d = 0.50$ ft., and the water depth above the step was 0.25 ft. ($D/d = 0.50$).

A number of additional tests were made, for values of d = 4, 5, 6, 7, 8 and 9 inches. The relationship between the Froude number and H_3/λ is shown in Fig. 7. The data shown in Fig. 7 and tabulated in Table 1 were obtained along the centerline in the direction of the plunger motion. These data are for a constant average plunger speed, V_{avg}, with different water depths. The two-dimensional results obtained by Garcia (1972) for a constant water depth, at x = 5 ft., are also shown in Fig. 7 for comparison. Although the location at which the measurements were made is different, it is still interesting to note that the relationship between H_3/λ and N_{Favg} has a less steep slope than is the case for the results from the two-dimensional tests. It also can be seen from Fig. 7 that for a constant Froude number the ratio H_3/λ tends to vary only slightly with λ/d within the range of variables tested. Furthermore, the ratio H_3/λ tends to be linearly related to the Froude number for values of Froude number between 0.3 and 0.4.

The variables affecting the ratio of the normalized crest elevation of the first wave for the 0.50 ft. wide plunger are the ratios, x/d, D/d, λ/d, the angle θ as defined in Fig. 5, and the Froude number. In order to study the relationship between H_3/λ and D/d, the other dimensionless variables were kept constant. The Froude number was kept constant by varying the plunger speed for different water depths. The desired plunger speed was obtained by using different weights that were dropped to move the plunger. To hold x/d and λ/d constant, a set of appropriate distances along the x axis and plunger displacements were chosen. The values of these parameters are given in Table 2. The results for different values of θ are shown in Fig. 8 and tabulated in Table 3. The locations at which the measurements were made are shown in Fig. 9.

The work described above (Table 3 and Fig. 8) was extended to include additional values of θ, up to 180 degrees. The results are shown in Tables 4 and 5 and in Fig. 10. A comparison of the results given in the three tables for values of $\theta = 0$, 15, 30, 45 and 60 degrees shows that the results are closely reproducible.

The curves shown in Fig. 10 were cross-plotted in Fig. 11. For large values of D/d, no data for $\theta > 135$ degrees are shown as there was no or very little water over the step and measurements were nearly meaningless. Note that for small values of D/d the curves of H/λ versus θ were approximately symmetrical about $\theta = 90$ degrees, but were very nonsymmetrical for large values of D/d. Examples of the wave records are given in Figs. 12 and 13. It can be seen for large values of D/d that the shape of the wave is different for $\theta = 15$ than for $\theta = 165$ degrees, etc. Thus, the phenomenon is more complicated than one might expect from an observation of Fig. 11.

With the same experimental setup that was used for the 0.50 ft. wide and 0.25 ft. deep plunger, additional tests were made using a step and plunger 2.00 ft. wide and 0.25 ft. high to obtain some information on the effect of the width of the source on the height of the crest of the leading wave. Unexpected difficulties were encountered in constructing and operating the wider step and plunger, so that insufficient data were obtained. However, enough data were obtained to be of some value in understanding the phenomenon.

The locations at which the waves were measured are shown in Fig. 14. The experimental results given in Table 6 were obtained along the centerline of the step. Comparing these data with the results obtained for the 0.50 ft. wide step (Table 2) shows that H_3 for the narrow ($W = 0.50$ ft.) step and plunger was about 35 percent of the value for the wide ($W = 2.00$ ft.) step and plunger for a value of D/d of about 0.40, and a little more than 55 percent of the value for D/d equal to 1.0 (Fig. 15), all other conditions being equal.

Fig. 16 shows that for $D/d < 0.5$ and $d/W > 1$, values of ratio H_3/λ are fairly independent of y for the narrow plunger. The first wave crests in this region, behave as if they came from a point source and are nearly independent of θ. The same tendency is apparent for the wide plunger for the smallest values of D/d for which tests were made. For large values of D/d the values of H_3/λ become quite nonuniform with respect to a constant value of r/d for both the narrow and wide plungers. It also can be seen that the waves behave as if they were generated by a combination of a line source and a point source for the case of W = 2.00 ft. for large values of D/d.

The plots of H_3/λ versus y shown in Fig. 16 for the W = 0.50 ft. plunger were shifted to the left by a value of 1.50 ft., and replotted in Fig. 17. The values are plotted as if the edge of the W = 0.50 and the W = 2.0 ft. plunger were along the same line. It is interesting to note the similarity of the two sets of data. It is also evident that the waves for the W = 2.00 ft. plunger were always higher than the waves for the W = 0.50 ft. plunger.

CONCLUSIONS

1. For the source mechanism tested, the wave crest elevation is considerably less for the three-dimensional case than for the two-dimensional case, with H_3/H_2 decreasing in proportion to $(x/d)^{-3/5}$ for $0.7 < x/d < 10$ and $W/d = 1.0$.

2. For small values of D/d the values of H_3/λ are fairly uniformly distributed with respect to θ for a given value of r/d, but become very nonuniform for large values of D/d.

3. Measurements of H_3 at a given value of r/d for various values of θ from 0 to 90 degrees showed that H_3 decreased in a nearly linear manner with the r sin θ, that is with the projection of the measurement point on the y axis, at least for the narrow (W = 0.50 ft.) source.

4. Values of H_3 along the centerline of the step and plunger were substantially higher for the wide (W = 2.00 ft.) source than for the narrow (W = 0.50 ft.) source, all other conditions being held constant.

5. Whether the plunger acts like line source or point source depends on the values of W/d and r/d.

ACKNOWLEDGMENTS

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NOTATION

d = undisturbed water depth (except over step and plunger), feet (or inches, as specified)

D = height of step (also plunger) above bottom of tank, feet

H_2 = elevation of first wave crest above SWL, 2-dimensional case, ft.

H_3 = elevation of first wave crest above SWL, 3-dimensional case, ft.

N_{Favg} = Froude number, $V_{avg}/\sqrt{gd}$, dimensionless

r = radius, measured from origin, $r^2 = x^2 + y^2$

SWL = still water level

t = time, seconds

V_{avg} = average velocity of plunger (λ/τ), feet per second

W = width of plunger, feet

x = horizontal distance along the side wall of the tank measured from the front end of the step, feet

y = horizontal distance normal to the side wall of the tank, feet

z = vertical coordinate

λ = total plunger displacement, feet (or inches, as specified)

τ = total time of plunger motion, seconds

θ = horizontal angle, measured counterclockwise from the centerline of the step, degrees

TABLE 1
Elevation of First Wave Crest Above SWL, as a Function of λ/d and $N_{F_{avg}}$ (W = 0.50 ft., θ = 0 degrees, and x = 1.00 ft.)

Water Depth d, inches	4			5			6		
Displacement λ, inches	6.82	5.75	4.50	6.82	5.75	4.50	6.82	5.75	4.50
$\frac{\lambda}{d}$	1.70	1.44	1.13	1.36	1.15	0.90	1.14	0.96	0.75
Wave Crest (measured) H, feet	0.066	0.054	0.040	0.046	0.037	0.027	0.038	0.039	0.022
$\frac{H_3}{\lambda}$	0.12	0.112	0.107	0.082	0.076	0.072	0.067	0.065	0.059
Froude Number	0.44	0.44	0.44	0.39	0.39	0.39	0.36	0.36	0.36
Water Depth d, inches	7			8			9		
Displacement λ, inches	6.82	5.75	4.50	6.82	5.75	4.50	6.82	5.75	4.50
$\frac{\lambda}{d}$	0.98	0.82	0.64	0.85	0.72	0.56	0.76	0.64	0.50
Wave Crest (measured) H_3 feet	0.034	0.027	0.020	0.027	0.023	0.015	0.024	0.020	0.015
$\frac{H_3}{\lambda}$	0.060	0.056	0.053	0.048	0.047	0.040	0.042	0.043	0.039
Froude Number	0.33	0.33	0.33	0.31	0.31	0.31	0.29	0.29	0.29

TABLE 2
Elevation of First Wave Crest Above SWL, as a Function of D/d
(W = 0.50 ft., x/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44, θ = 0 degrees and W/d = 2.0)

Water Depth d inches	Distance Along x Axis x, feet	Displacement of Step Motion λ, inches	Displacement Velocity of plunger V_{avg}, ft/sec	Weight Used To Cause Motion lbs lbs	Wave Crest Elevation at x H_3 feet	$\frac{H_3}{\lambda}$	$\frac{D}{d}$
3	0.75	2.25	1.25	1.8	0.034	0.18	1.00
4	1.00	3.00	1.44	8.2	0.021	0.086	0.75
5	1.25	3.75	1.61	19.5	0.017	0.055	0.60
6	1.50	4.50	1.77	34.0	0.014	0.037	0.50
7	1.75	5.25	1.90	75.0	0.012	0.028	0.43
8	2.00	6.00	2.04	100.0	0.012	0.022	0.38
9	2.25	6.75	2.16	121.0	0.010	0.018	0.33

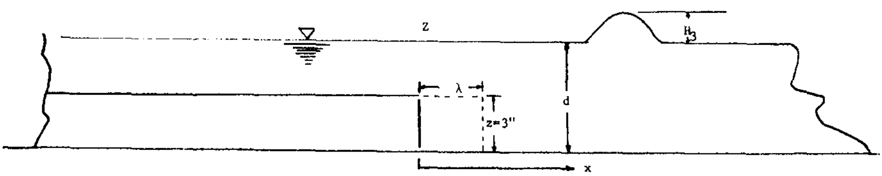

TABLE 3

Elevation of First Wave Crest Above SWL, as a Function of D/d and θ
(W = 0.5 ft., r/d = 3.0, λ/d = 0.75 N_{Favg} = 0.44 and W/D = 2.0)

Water Depth d inches	Elevation of First Wave Crest at r/d = 3.0, H_3 (feet)					$\frac{H_3}{\lambda}$					$\frac{D}{d}$
	0°	15°	30°	45°	60°	0°	15°	30°	45°	60°	
3	0.034	0.027	0.025	0.019	0.014	0.18	0.14	0.13	0.099	0.075	1.00
4	0.021	0.019	0.016	0.013	0.011	0.086	0.077	0.064	0.054	0.042	0.75
5	0.017	0.015	0.013	0.011	0.009	0.055	0.049	0.042	0.035	0.029	0.60
6	0.014	0.012	0.011	0.009	0.008	0.037	0.033	0.029	0.025	0.021	0.50
7	0.012	0.011	0.010	0.008	0.007	0.027	0.025	0.022	0.018	0.016	0.43
8	0.012	0.010	0.009	0.008	0.006	0.022	0.020	0.017	0.015	0.013	0.38
9	0.010	0.009	0.008	0.006	0.006	0.018	0.016	0.014	0.011	0.011	0.33

TABLE 4

Elevation of First Wave Crest Above SWL, as a Function of θ (0 to 180 degrees), Plunger Displacement and Water Depth (W = 0.5 ft., r/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44 and W/D = 2.0)

Water Depth d inches	Elevation of First Wave Crest Above SWL, H_3, feet													Displacement of Plunger
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	λ inches
3	0.037	0.031	0.025	0.019	0.013	0.010	0.008	0.006	0.005	0.004				2.25
4	0.021	0.019	0.016	0.013	0.010	0.009	0.007	0.006	0.006	0.007	0.006			3.00
5	0.018	0.016	0.014	0.011	0.010	0.008	0.007	0.006	0.007	0.008	0.007	0.010		3.75
6	0.015	0.014	0.012	0.010	0.008	0.007	0.006	0.006	0.007	0.009	0.009	0.009	0.011	4.50
7	0.013	0.012	0.011	0.009	0.008	0.006	0.005	0.005	0.006	0.009	0.009	0.009	0.014	5.25
8	0.012	0.010	0.009	0.008	0.007	0.006	0.005	0.005	0.007	0.009	0.010	0.011	0.013	6.00
9	0.010	0.009	0.008	0.007	0.006	0.005	0.004	0.004	0.006	0.009	0.010	0.011	0.012	6.75

TABLE 5

Normalized Elevation of First Wave Crest Above SWL, as a Function of θ (0 to 180 degrees) and D/d (W = 0.5 ft., r/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44 and W/D = 2.0)

Water Depth d inches	H_3/λ													$\frac{D}{d}$
	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	
3	0.200	0.168	0.132	0.102	0.069	0.054	0.042	0.030	0.024	0.023				1.00
4	0.086	0.077	0.065	0.054	0.041	0.35	0.028	0.023	0.025	0.027	0.025			0.75
5	0.057	0.050	0.045	0.036	0.031	0.026	0.022	0.020	0.022	0.026	0.022	0.038		0.60
6	0.041	0.037	0.032	0.028	0.022	0.019	0.017	0.016	0.018	0.024	0.024	0.025	0.030	0.50
7	0.031	0.028	0.024	0.021	0.018	0.014	0.012	0.011	0.014	0.020	0.021	0.021	0.032	0.43
8	0.023	0.020	0.018	0.015	0.013	0.011	0.010	0.010	0.013	0.018	0.020	0.022	0.026	0.36
9	0.018	0.016	0.015	0.013	0.011	0.009	0.008	0.008	0.011	0.015	0.017	0.020	0.022	0.33

Table 6

Elevation of First Wave Crest Above SWL, as a Function of D/d
(W = 2.0 ft., x/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44, θ = 0 degrees, W/D = 8.0)

Water Depth d Inches	Distance Along x Axis, x ft.	Displacement of Plunger λ inches	Displacement Velocity of Plunger Motion Vavg, ft/sec.	Weight used to cause motion lbs.	Wave Crest Elevation at x, feet	$\frac{H_3}{\lambda}$	$\frac{D}{d}$
3	0.75	2.25	1.25	24.0	0.059	0.318	1.00
4	1.00	3.00	1.44	53.0	0.051	0.205	0.75
5	1.25	3.75	1.61	84.0	0.045	0.145	0.60
6	1.50	4.50	1.77	110.0	0.037	0.010	0.50
7	1.75	5.25	1.90	134.0	0.034	0.078	0.43
8	2.00	6.00	2.04	156.0	0.031	0.062	0.38

Note: No measurements were made for a water depth of 9 inches

TABLE 7

Elevation of First Wave Crest Above SWL, as a Function of (x,y) and Water Depth
(W = 2.00 ft., x/d = 3.0 for 3" < y < 21" and r/d = 3.0 for y > 21", θ/d = 0.75, N_{Favg} = 0.44 and W/D = 8.0)

Water Depth d Inches	Elevation of First Crest Above SWL, H_3, test along y Direction												
	y = 3 inches	6	9	12	15	18	21	21+ xSin15°	21+ xSin30°	21+ xSin45°	21+ xSin60°	21+ xSin75°	x inches
3	.060	.060	.060	.056	.053	.049	.042	.035	.028	.022	.018	.013	9
4	.056	.056	.056	.051	.047	.043	.037	.029	.023	.018	.014	.010	12
5	.050	.050	.049	.045	.042	.038	.033	.025	.019	.016	.012	.010	15
6	.046	.044	.042	.038	.036	.030	.029	.022	.017	.013	.009	.008	18
8	.040	.038	.037	.034	.031	.027	.024	.021	.018	.014	.010	.009	24

Table 8

Normalized Elevation of First Wave Crest Above SWL, as a Function of θ
(W = 2.0 ft., x/d = 3.0 for 3" < y < 21" and r/d = 3.0 for y > 21", λ/d = 0.75, N_{Favg} = 0.44 and W = 8.0)

Water Depth d inches	$\frac{H_3}{\lambda}$												$\frac{D}{d}$
	y = 3 inches	6	9	12	15	18	21	21 + Sin15°	21 + Sin30°	21 + Sin45°	21 + Sin60°	21+ Sin 75°	
3	0.322	0.322	0.322	0.300	0.285	0.260	0.223	0.186	0.150	0.118	0.099	0.068	1.00
4	0.223	0.223	0.223	0.206	0.187	0.171	0.149	0.117	0.093	0.071	0.058	0.040	0.75
5	0.160	0.160	0.156	0.146	0.136	0.121	0.107	0.080	0.062	0.052	0.039	0.033	0.60
6	0.123	0.116	0.111	0.103	0.097	0.082	0.077	0.059	0.045	0.035	0.025	0.022	0.50
8	0.080	0.077	0.074	0.069	0.062	0.056	0.048	0.041	0.035	0.029	0.020	0.017	0.36

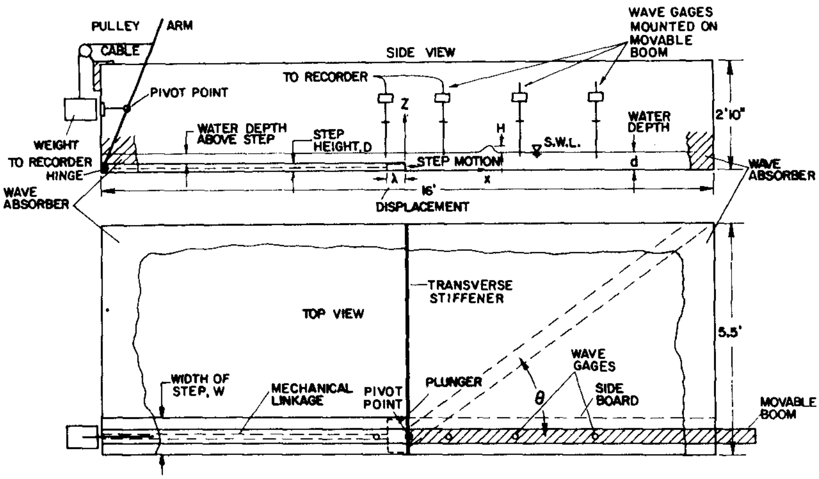

FIG. 1 EXPERIMENTAL ARRANGEMENTS

MEASURED WAVE ELEVATION ABOUT SWL

DISTANCE ALONG FLUME, ft.	-0.5	0.33	1.0	2.0	2.5
ELEVATION ABOUT SWL, ft.	0.025	-0.05	0.016	0.034	0.014

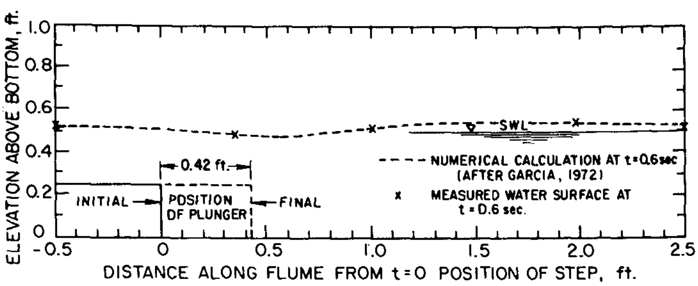

FIG. 2 MEASURED WATER SURFACE PROFILE FOR WAVE GENERATED BY HORIZONTAL MOTION OF SUBMERGED STEP, COMPARED WITH THEORY, TWO-DIMENSIONAL MODEL, PLUNGER DISPLACEMENT = 0.42 ft., FROUDE NUMBER = 0.32, AND d/W = 1.0

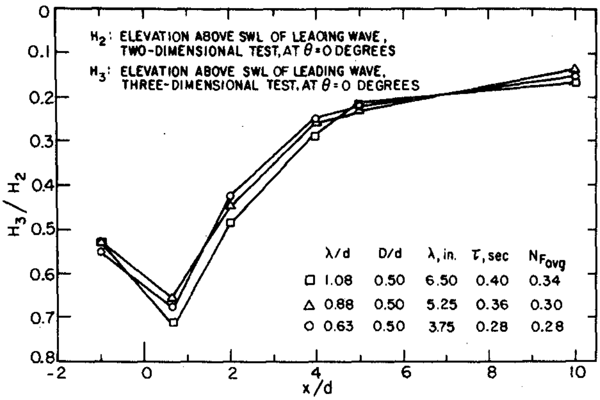

FIG. 3 H_3/H_2 VERSUS x/d, FOR W=0.50 FT., d/W=1.0
(FROM LIU AND WIEGEL, 1974)

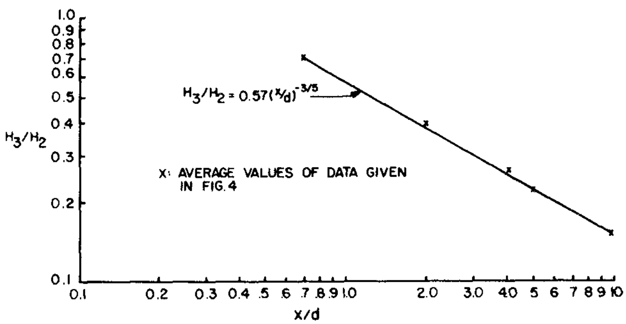

FIG. 4 H_3/H_2 VERSUS x/d FOR W= 0.50 FT. AND d/w = 1.0

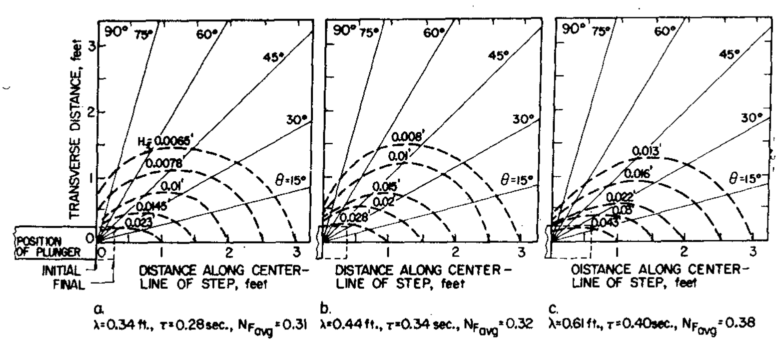

FIG. 5 CONTOURS OF EQUAL CREST ELEVATION ABOVE S.W.L. (D/d=0.50, d/W=1.0, d=0.50 FT., W=0.50 FT.) (FROM LIU AND WIEGEL, 1974)

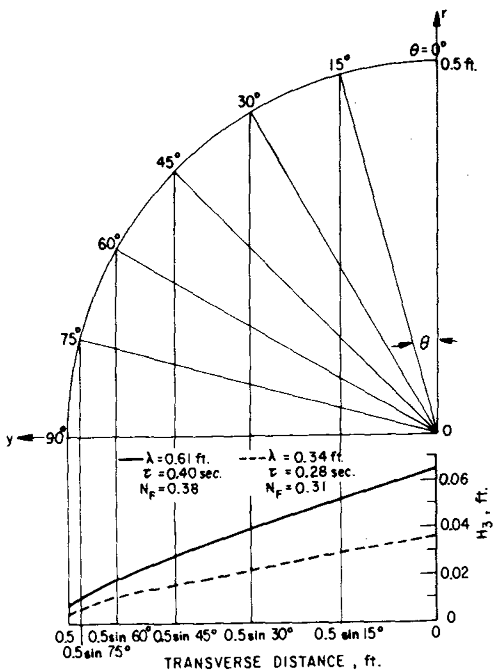

FIG. 6 ELEVATION OF FIRST WAVE CREST ABOVE SWL AT r = 0.50 FT. RADIUS VS PROJECTION ONTO THE TRANSVERSE AXIS, W = 0.50 FT. (FROM LIU AND WIEGEL, 1974)

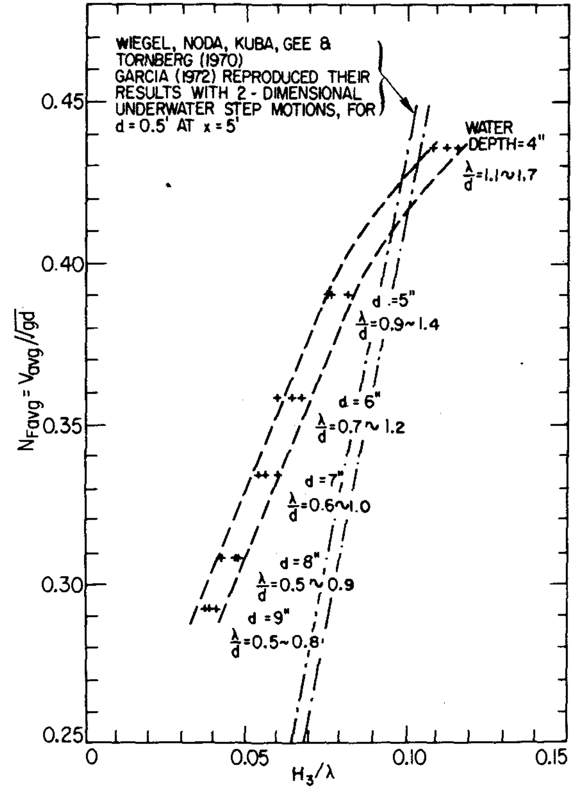

FIG. 7 RELATIONSHIP BETWEEN H_3/λ AND N_{Favg} $(V_{avg}/\sqrt{gd})$ FOR UNDERWATER 3-DIMENSIONAL STEP MOTIONS FOR W = 0.50 FT., d = 4" TO 9", O = 0.25 FT. AND x = 1.0 FT.

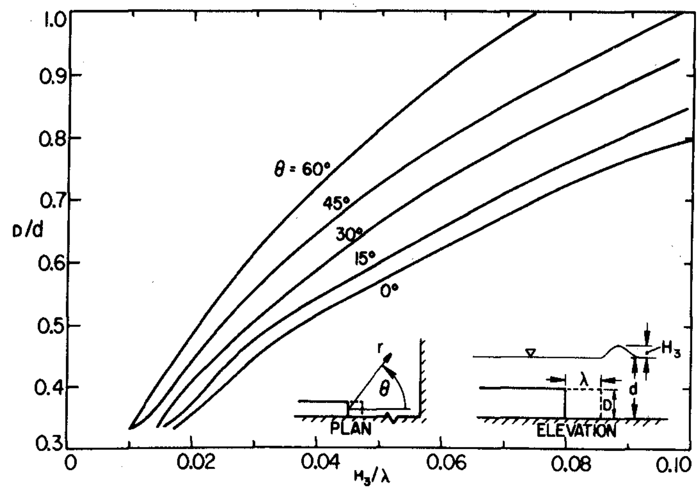

FIG. 8 RELATIONSHIPS AMONG H_3/λ, D/d AND θ, FOR N_{Favg}=0.44, r/d=3.0, λ/d=0.75, AND W=0.50 FT.

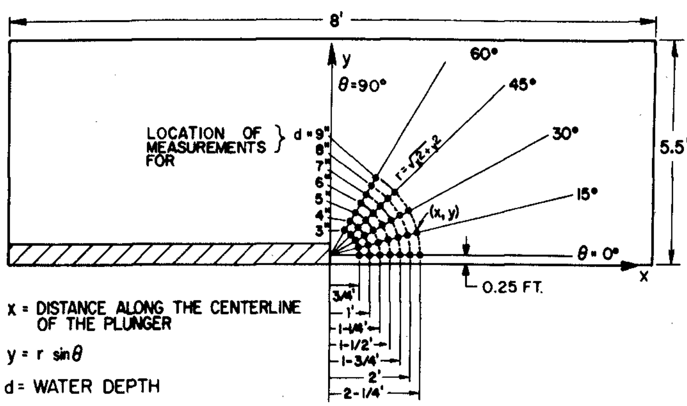

FIG. 9 LOCATIONS AT WHICH MEASUREMENTS WERE MADE OF THE WAVE TIME HISTORIES FOR THE 0.50 FT. WIDE PLUNGER

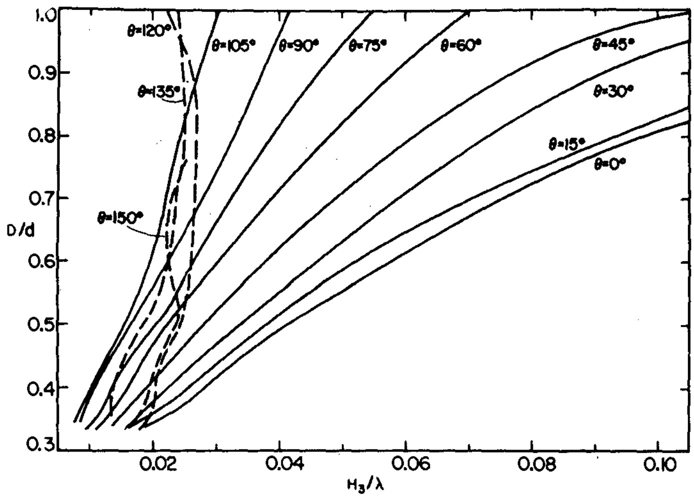

FIG. 10 RELATIONSHIP BETWEEN H_3/λ AND D/d AS A FUNCTION OF θ, FOR r/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44, AND W = 0.50 FT.

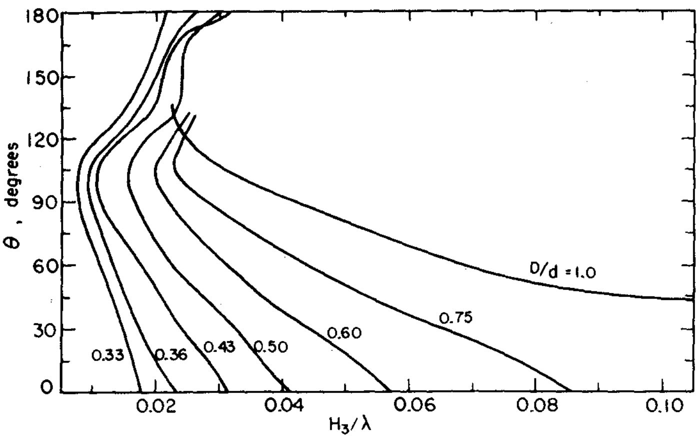

FIG. 11 RELATIONSHIP BETWEEN H_3/λ AND θ AS A FUNCTION OF D/d FOR r/d = 3.0, λ/d = 0.75, N_{Favg} = 0.44, AND W = 0.50 FT.

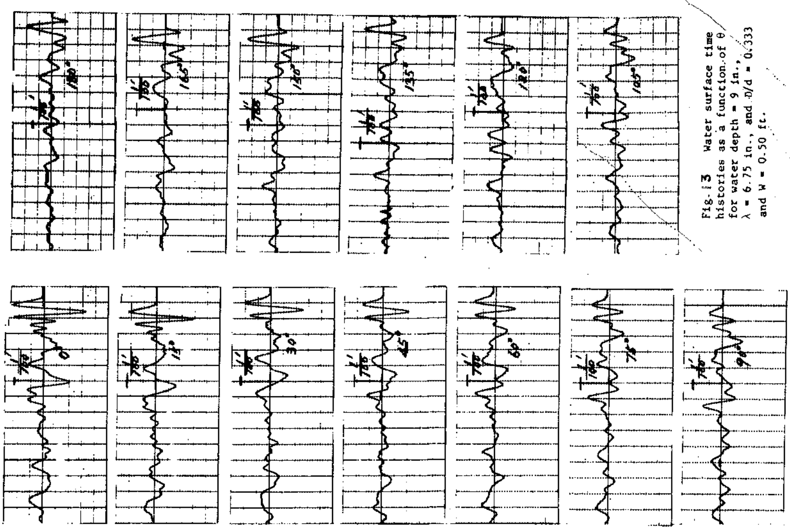

Fig. 13 Water surface time histories as a function of θ for water depth = 9 in., λ = 6.75 in., and D/d = 0.333 and W = 0.50 ft.

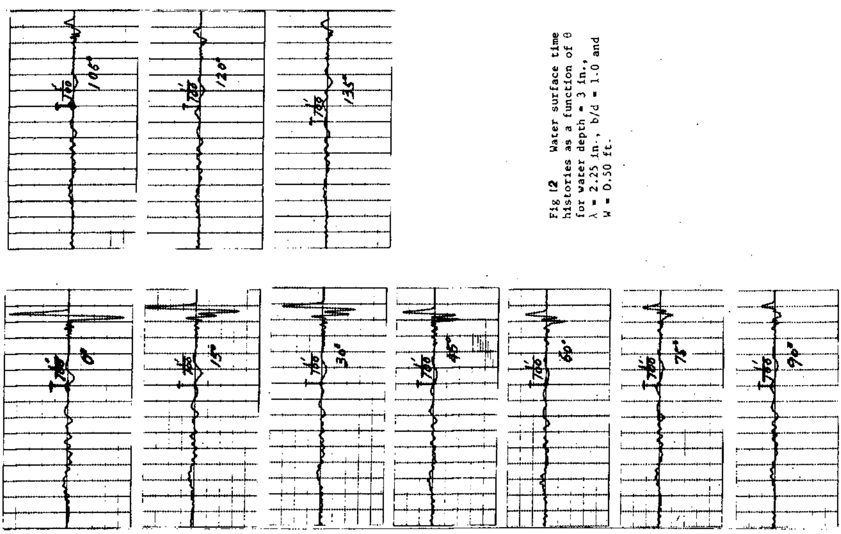

Fig 12 Water surface time histories as a function of θ for water depth = 3 in., λ = 2.25 in., b/d = 1.0 and W = 0.50 ft.

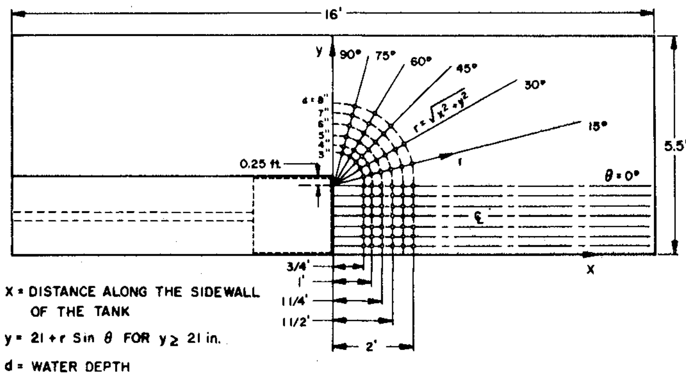

FIG. 14 LOCATIONS AT WHICH MEASUREMENTS WERE MADE OF THE WAVE TIME HISTORIES FOR THE 2.0 FT. WIDE PLUNGER

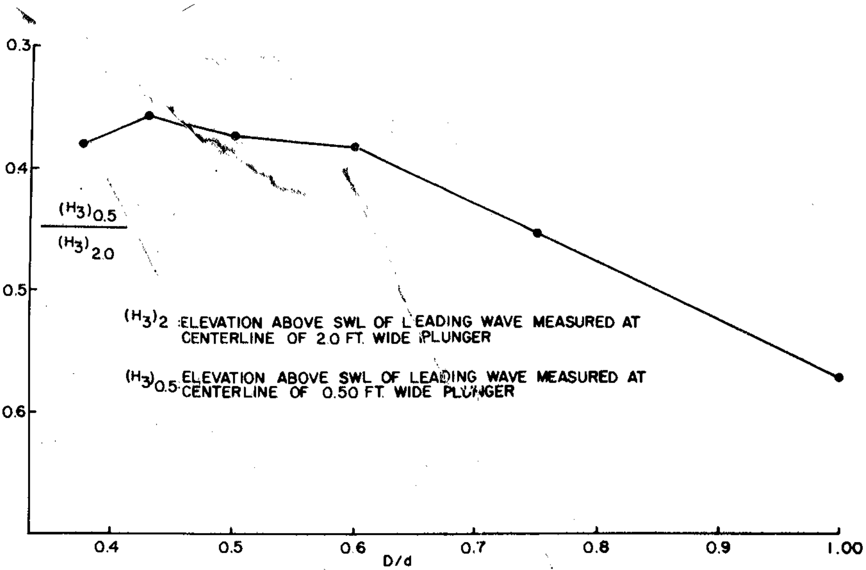

FIG. 15 $(H_3)_{0.5}/(H_3)_{2.0}$ VERSUS D/d FOR $x/d=3.0$, $\lambda/d=0.75$, $N_{F avg}=0.44$ AND $\theta=0°$

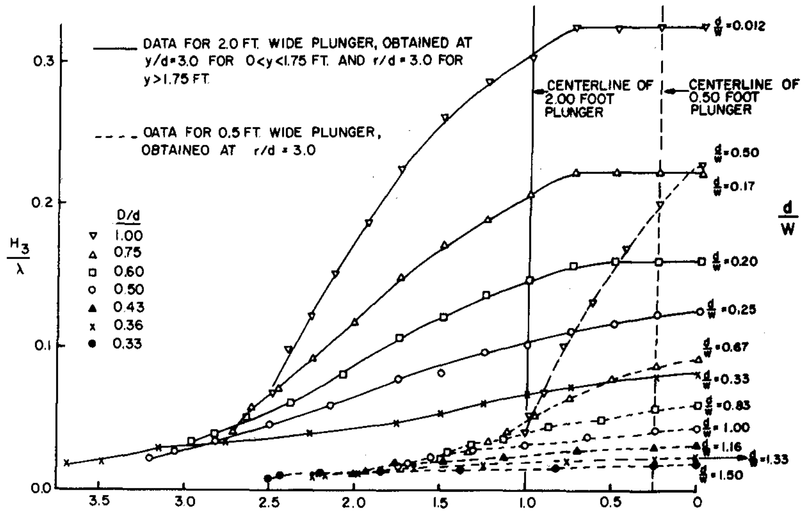

FIG. 16 COMPARISON OF H_3/λ VERSUS y FOR THE NARROW PLUNGERS FOR SEVERAL VALUES OF d/W AND D/d, WITH N_{Favg} = 0.44

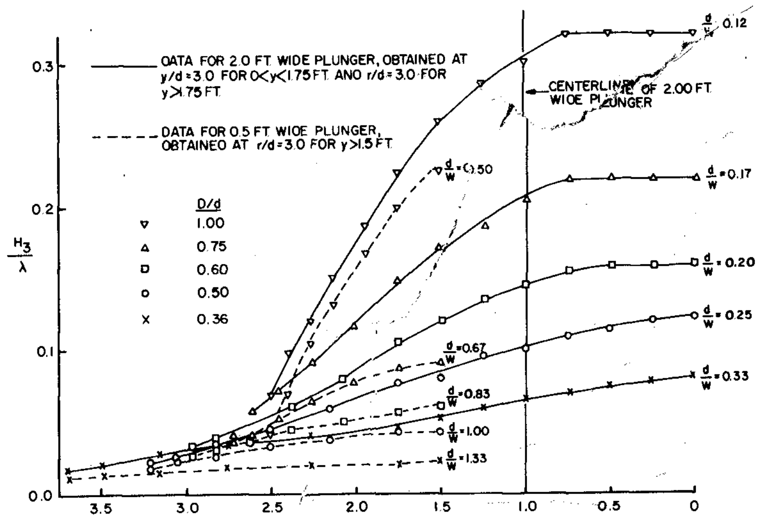

FIG. 17 COMPARISON OF H_3/λ VERSUS y FOR THE WIDE AND NARROW PLUNGERS FOR SEVERAL VALUES OF d/W AND D/d, WITH N_{Favg} = 0.44. THE VALUES FOR W=0.5 FT. DISPLACED 1.5 FT.