PRESENTED AT THIRD SESSION OF THE EIGHTH MEETING OF THE AMERICAN TOWING TANK CONFERENCE AT TH UNIVERSITY OF MICHIGAN - WEDNESDAY, 13 OCTOBER 1948 AT 9:00 A.M.

SOME ASPECTS OF SEAWORTHINESS TESTS

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For many years the ship model towing tanks of the world have been primarily interested in the still water resistance of ship forms, and testing techniques have been perfected which will permit quite accurate evaluations of this quantity. A large mass of data has been obtained and is now being collected and sorted out so that we will be able to predict from former tests what the effect on resistance will be when any one of a number of changes are made in the hull form.

In regard to rough water tests of ship model, however, a thorough exploration of hull forms has not yet been made. The hull form above the water line becomes doubly important in rough water tests and very few tests have taken this matter into consideration. At this point it might be of value to suggest that the whole technique of towing ship models in rough water or waves, especially when the linear ratio between ship and model is large, be carefully scrutinized for misleading effects which would yield ridiculous results. In still water towing, we have developed the proper respect for such powerful effects as transitional and laminar flow on our model hulls. It is quite probable that similar misleading effects will arise in rough water towing of small models as the activities in this field increase. With due regard to what our answers mean when translated to prototype size, we may hope to avoid the criticism which, at the present time, is aimed at shallow water and certain other types of model tests. As an example of this, we might quote Mr. E. Wilding's discussion of a paper presented in 1934 to the Institution of Naval Architects. In commenting on the failure of tank predictions of shallow water resistance, he said, " I have come to the conclusion that the experimental published data so far as they are accessible in this country for all shallow-water work at speeds of about 70 per cent of the critical speed (i.e., of the wave translation) are frankly not worth the paper they are written on."

In the last few years an increase in the proportion of rough water tests has been noted as more tanks become equipped with wave-making devices. Since the Newport News tank has been making rough water tests since 1933, it was thought that an account of some of these tests would show the variety of work encountered and the type of experimental result obtained.

The gravity type of towing mechanism which is used in the Newport News tank lends itself very well to ship model towing in waves. This equipment and the wavemaker have been described in papers presented to the Society of Naval Architects. The gravity system allows a constant thrust to be applied to the model by placing a definite weight on the weight pans. To increase the thrust to a larger or smaller constant amount, a greater weight or a lesser weight is used.

One feature of runs in which pronounced pitching occurs, is relatively long fluctuations in speed, caused by cycles of heavy and moderate pitching. Since the accompanying graphs are plotted with a single line to show speed versus wavelength, it is important to mention that the points through which the curves are drawn are the average values of speeds encountered during one run. Presumably similar fluctuations of speed would be experienced by the ship, and these results are probably more comparable to ship results than would be obtained by towing the model from a carriage at an unchanging speed. In this matter, however, it is probable that a short, gravity type of dynamometer could be arranged to run the length of a carriage and used in conjunction with it, thus allowing the operators of large towing tanks to have the advantages of both systems simultaneously.

The methods of obtaining pitching angle, vertical accelerations and other experimental quantities are described in great detail in the papers mentioned above, therefore, this account will be restricted to a description of the experimental results.

A whole set of desirable seaworthiness characteristics for merchant ships can be drawn up quite easily by any naval architect and our naval ship designers, due to recent developments in scientific warfare are also prepared to draw up in detail, an entirely different criterion of seaworthiness which will suit their special needs. In our experience, the quantity which is usually requested in our tests is "loss of speed in head seas." A little reflection on the economics of merchant ship operation will make it evident why this quantity is so important. The next most important result desired is the rolling behavior. Pitching angle, vertical acceleration and heave follow in about that order.

An inspection of the accompanying graphs will show that a ship encountering head seas will encounter a moderate reduction (approximately 10 per cent) in speed at wave lengths of about 75 per cent of the length of the ship. This condition rapidly changes until at wavelengths equal to the length of the ship, and at a thrust equivalent to design speed in still water, the maximum reduction of speed is obtained and amounts to approximately 50 or 60 per cent. Recovery of speed as the wavelength increases beyond the length of the ship is more gradual and it is usually noted that in waves of twice the length of the ship there is still a speed reduction of from 15 to 20 per cent. Since these wavelengths are of the order of 1000 to 2000 feet, the chances of their occurrence would be remote and so no particular study has been made of them.

The effect of reducing the speed of the ship in head seas and proceeding under less than full power, is one of the usual precautions against damage to the ship and its cargo, and is shown in the accompanying graph on the effect of flare. Four different speed length ratios are chosen and speed reduction versus wavelength is shown.

The results indicated on the graph show that in waves up to half the length of the ship, an unusual amount of flare very definitely slows up the ship. The least flare causes the least speed reduction. From this point on, through the region of violent pitching, no decided superiority can be noted for any of the three amounts of flare. One result of this test which is of interest is the recovery of speed shown in the lower right hand corner of the graph. The ship which was proceeding slowly at a still water speed of 13.8 knots begins to recover speed sooner than when it was developing greater thrusts.

This short study of flare, incidentally, points up the fact t hat experiments with ship models in waves usually result in alterations to the bow form. The experimenters, on the basis of visual observations, usually decide that bulbous bows, forefoot sections, flare at the bow and other considerations involving the forward portion of the hull form are the logical first steps in a seaworthiness investigation. The writer agrees with this view, but would like to stress the point that, in his opinion, bow form is only half the problem. Flat counter or "motor boat" sterns, Vee sterns, after sections of great displacement and other features involving the hull form aft of amidships will inevitably contribute to the action in waves of the bow. Suitable comparative types of testing, however, can isolate these effects so that each may be studied separately with fair success. An example of this is the study of a Maierform bow in the Newport News tank. In this work two models were towed under identical wave conditions. One model had a Maierform bow and stern sections similar to the normal model. On the basis of visual observations and notes, pitching angle records obtained by the photographic light-trace method, slow-motion moving pictures and speed records of each run, it was concluded that:

1. The normal model showed less speed reduction than the Maierform up to the point where these models encountered waves of one model length.
2. In waves of their own length both models have about the same speed reduction but the normal lines show somewhat higher pitching angle (30 per cent).
3. In longer waves, the Maierform model is superior because in spite of higher pitching angles it is pitching with the oncoming waves with better speed and drier decks than the original model.

A further graph sheet, accompanying this report, illustrates the variation in pitching angle, vertical acceleration at the bow and speed reduction for one model at various wave lengths. It will be noted that all these quantities reach a maximum at a wavelength of about 700 feet. This figure is somewhat longer than the length of the ship.

Another type of rough water test is that which concerns rolling. A recent problem at the Newport News tank was to investigate the roll damping produced by free water in one hold of an LST which was being converted to a vehicle ferry. Part of the problem was to find the minimum dimensions for the holes which were to be cut in the longitudinal bulkheads and through which the water would be allowed to flow as the ship rolled. The graph sheet shows that two feet of water in this hold reduces the rolling angle, as compared to a dry hold, by 22 per cent. The proximity of the four "wet" curves to each is somewhat surprising since it indicates that the size of openings in the longitudinal bulkheads had very little effect on the rolling characteristics. The accompanying photograph shows the LST model rolling in a beam sea.

A somewhat unusual test, which may be classed with the seaworthiness tests, is that performed on a ship's swimming pool. The liner "S.S. America" had experienced numerous storms and it was noted that a large surging action was present in the swimming pool when the ship was pitching moderately. During extensive repairs to t he ship in Newport News it was requested that we devise suitable wave traps or gutters to damp this surge. Many devices were tried in a model pool, which was caused to pitch in a manner similar to the prototype on the ship, but none were effective. During these tests it was noted that length, depth and pitching period could be combined to produce violent resonance effects. Further investigation proved that the natural period of the pool approached that of the ship's pitching period. By shortening the pool from 33 to 30 feet, enough difference in surge amplitude was produced to keep the water in the pool. An experiment was made to satisfy scientific curiosity by oscillating the model pool at the resonant point. Violent effects were obtained as shown in the accompanying photograph. The other two photographs of the model pool show a "before" condition in which the water spills over one end of the 33-foot tank and an "after" condition in which this does not occur in a 30-foot tank.

Two additional photographs of an airplane carrier in a heavy sea show the forward section of the flight deck emerging and immersing in the sea. This test was performed for the purpose of studying the water loads on the forward corners of the flight deck. As a result of this work which included analysis of an extensive series of slow motion moving pictures and other testing techniques, alterations were made to allow a better solution to the structural problem involved.

In conclusion, the writer would like to make some recommendations and a proposal concerning future work on seaworthiness.

It is felt that isolated and unrelated tests by various towing tanks of specific hull forms of proposed ships will not yield general design information. To obtain the greatest benefits, a systematic schedule should be set up for comprehensive rough-water testing.

A necessary preliminary step would be to tow a single ship model in a large variety of test conditions for the purpose of discovering the probable variables which might enter into a quantitative evaluation of the seaworthiness criterion. After this is accomplished, several systematic series of models could be towed to obtain the quantitative data for each variable. As a start in this fundamental research, the following series could be set up:

1. FLARE SERIES

Determine the effect of the amount of flare and type of flare at the bow of a ship on speed reduction, amount of water on deck, pitching angle and vertical accelerations. Determine impact forces on shell plating of bow sections.

2. RADIUS OF GYRATION SERIES

Determine the effect of varying the longitudinal radius of gyration, over wide limits, on several forms of vessels whose beam/draft ratio and prismatic coefficients are also varied over wide limits. Tow in head seas to obtain measurements as in (1) above.

3. AFTERBODY SERIES

Investigate the effect of varying the afterbody form of hulls on seaworthiness.

4. FREEBOARD SERIES

Vary the freeboard of a model through a wide range of vertical and horizontal alterations to determine its seaworthiness as in (1) above.

5. STEM SHAPE SERIES

Vary in a methodical manner, the profile and bow sections of a series of ship models and tow in a variety of rough water conditions to discover what effect these changes will have on seaworthiness. Variations of model form to include such items as Vee sections, raked and knuckle stem profiles, Maierform bows and bulbous bows.

6. REGULAR WAVE SERIES

Investigate the action, on a variety of ship model forms, which results from a variation of the length/height ratio of regular waves. In addition to obtaining data on speed reduction, pitching angle, vertical acceleration and amount of water on deck, make measurements of speed variations in a single cycle of pitching for the purpose of evaluating the force vectors which are produced.

7. IRREGULAR WAVE SERIES

Determine experimentally the practicality of generating and calibrating a confused sea in the model tank in which to tow ship models and which is more nearly a simulation of actual sea conditions. Tow ship models and collect sufficient data on pertinent variables to allow an analysis to be made which will prove or disprove the value of this idea.

8. EQUIPMENT AND TECHNIQUE SERIES

Prepare a series of reports which describe in detail the rough-water equipment and methods used by laboratories both here and abroad. These reports to include such items as wave profile measurements, wavemaker machinery, instruments for measuring height and length of model basin waves, towing attachments allowing free pitching or free rolling, accelerometer design, calibration and use, photographic methods used in seaworthiness tests.

9. EXTENDED SERIES

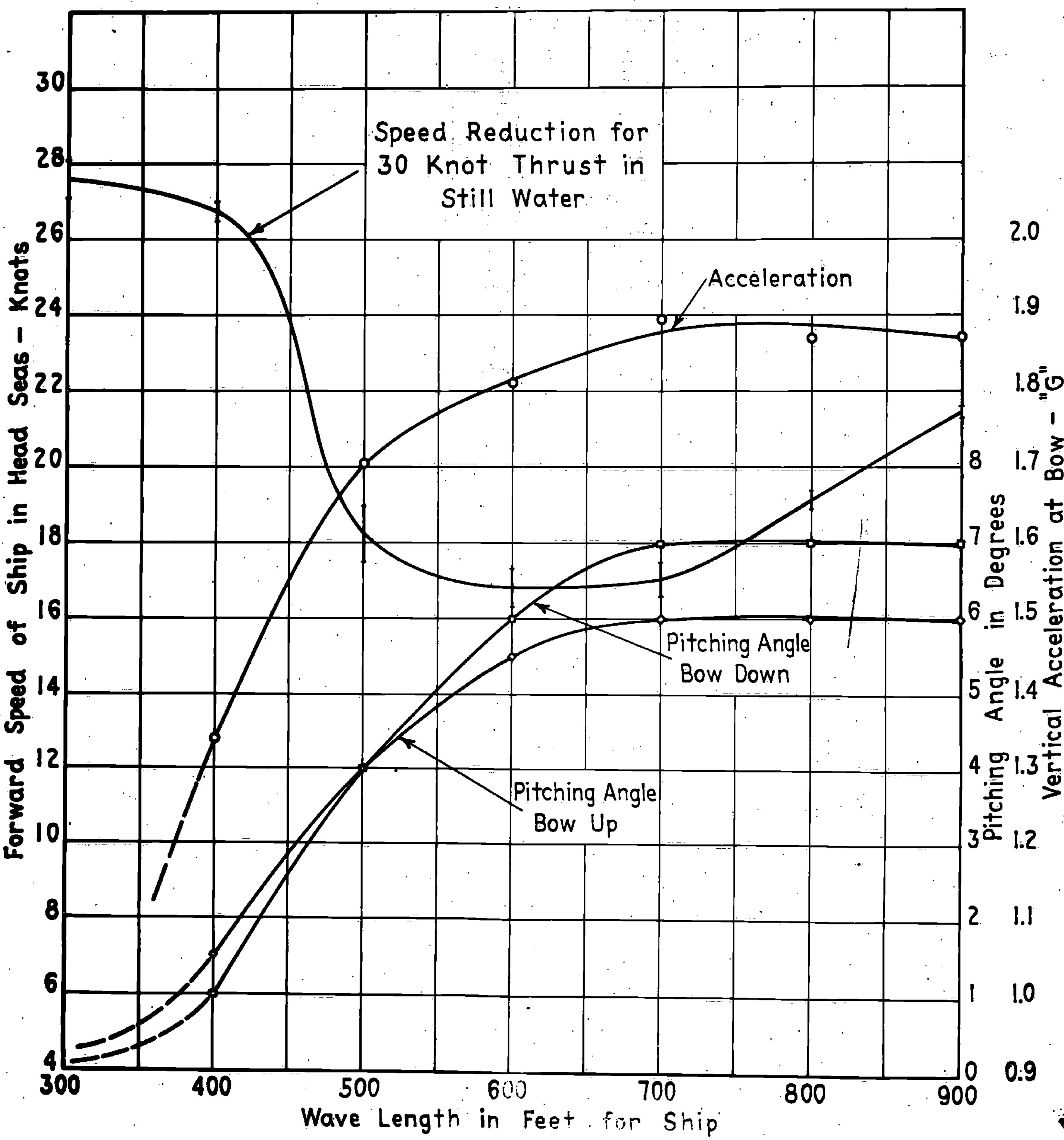
Review the work accomplished in Series 1 through 7 above, which is primarily concerned with the action of a ship in head seas, and extend the work in each series as it appears practical by repeating the work in quartering seas and beam seas.

This outline of rough water towing is intended to provoke discussion on possible omissions and oversights. It may also cause comment on the tremendous amount of work involved, too. This brings us to the proposal mentioned above.

It is proposed that a permanent Seaworthiness Committee be appointed by the American Towing Tank Conference for the purpose of considering the work outlined above, the feasibility of undertaking it or some variation of it and the supervision of the subsequent activity in this field if such should result.

The Committee appointed, to report annually to the American Towing Tank Conference on the progress of the seaworthiness work under its supervision.

The purpose of proposing such a committee is to insure the cooperation of all North American towing tanks in this program. The work which has been done on the subject of seaworthiness to date is meager and uncorrelated. By an organized effort of all towing tank establishments at this time much repetition in the future can be eliminated. The prompt exchange of information, which such a committee would make possible, would be a distinct advantage to all towing tanks. Towing tank operators who do not have wave-making equipment at the present time would be encouraged to install such equipment if the committee proved in their reports to the Conference that such activity would yield results of value. The whole field of rough-water towing of ship models has only recently been entered and a tremendous amount of work remains to be done in it. It is logical to map out this work now rather than twenty or thirty years hence when much of this work will have been accomplished.



Speed Reduction for 30 Knot Thrust in Still Water
Acceleration
Pitching Angle Bow Down
Pitching Angle Bow Up
Forward Speed of Ship in Head Seas - Knots
Pitching Angle in Degrees
Vertical Acceleration at Bow - "G"
Wave Length in Feet for Ship
300
400
500
600
700
800
900
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
1
2
3
4
5
6
7
8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
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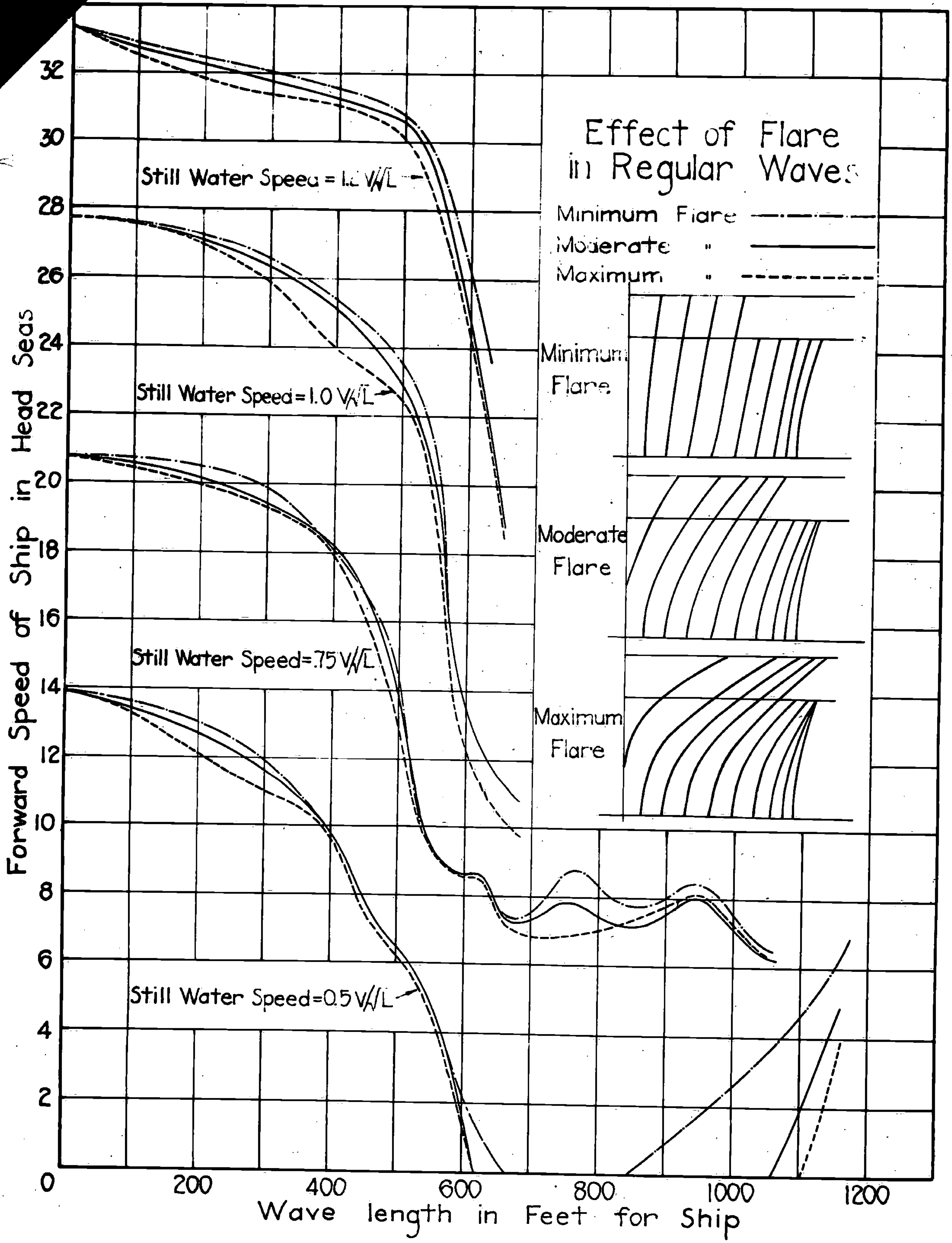
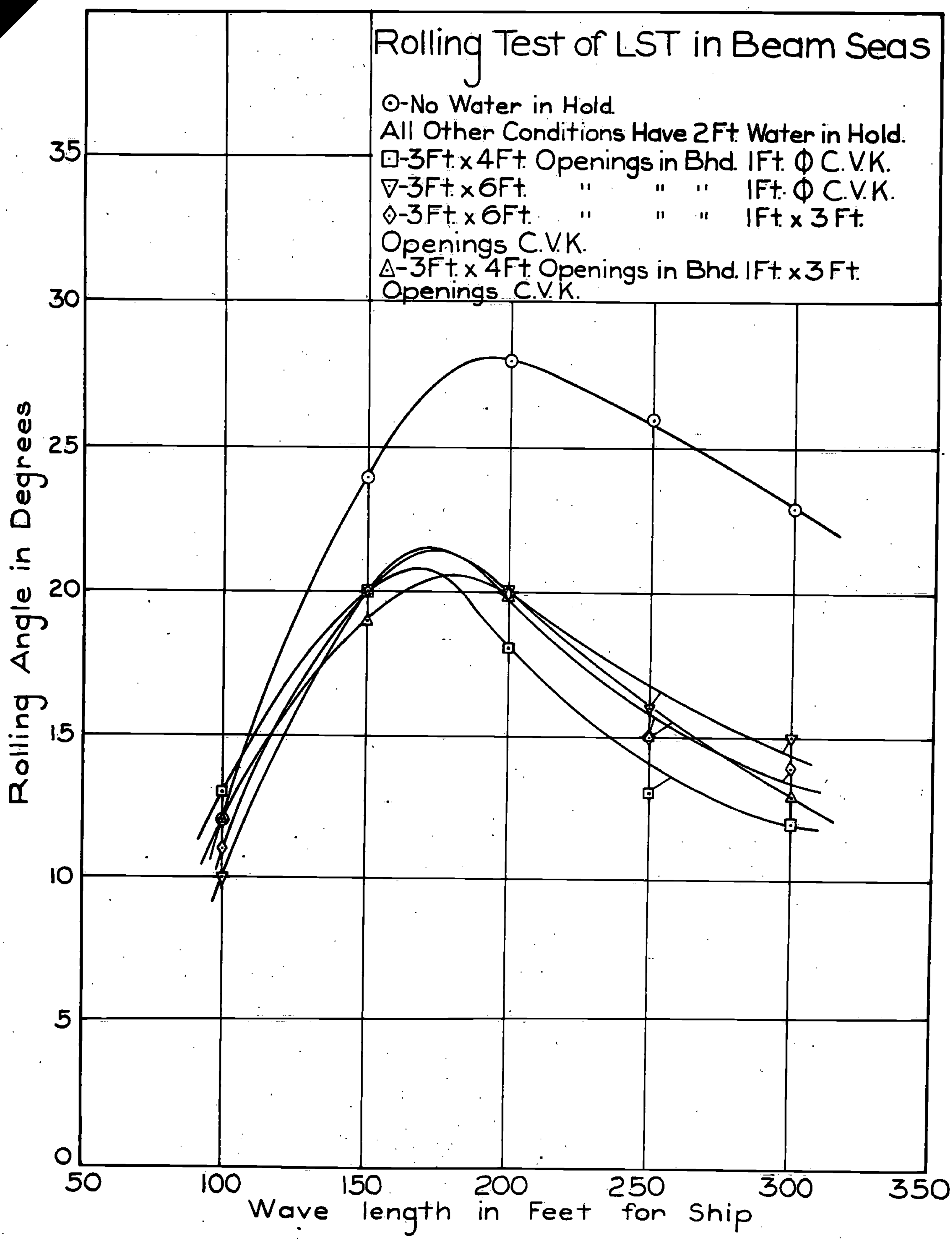
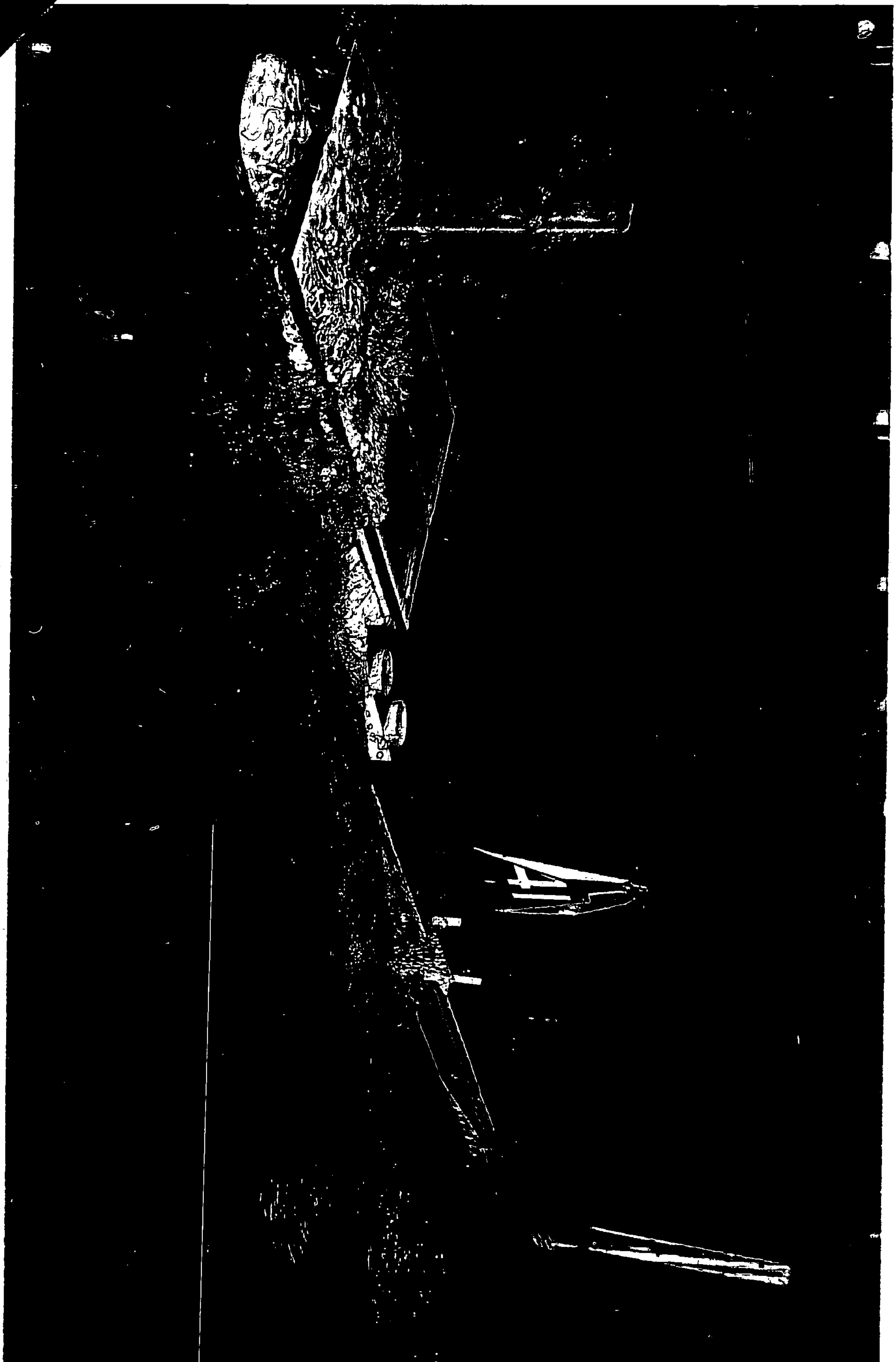
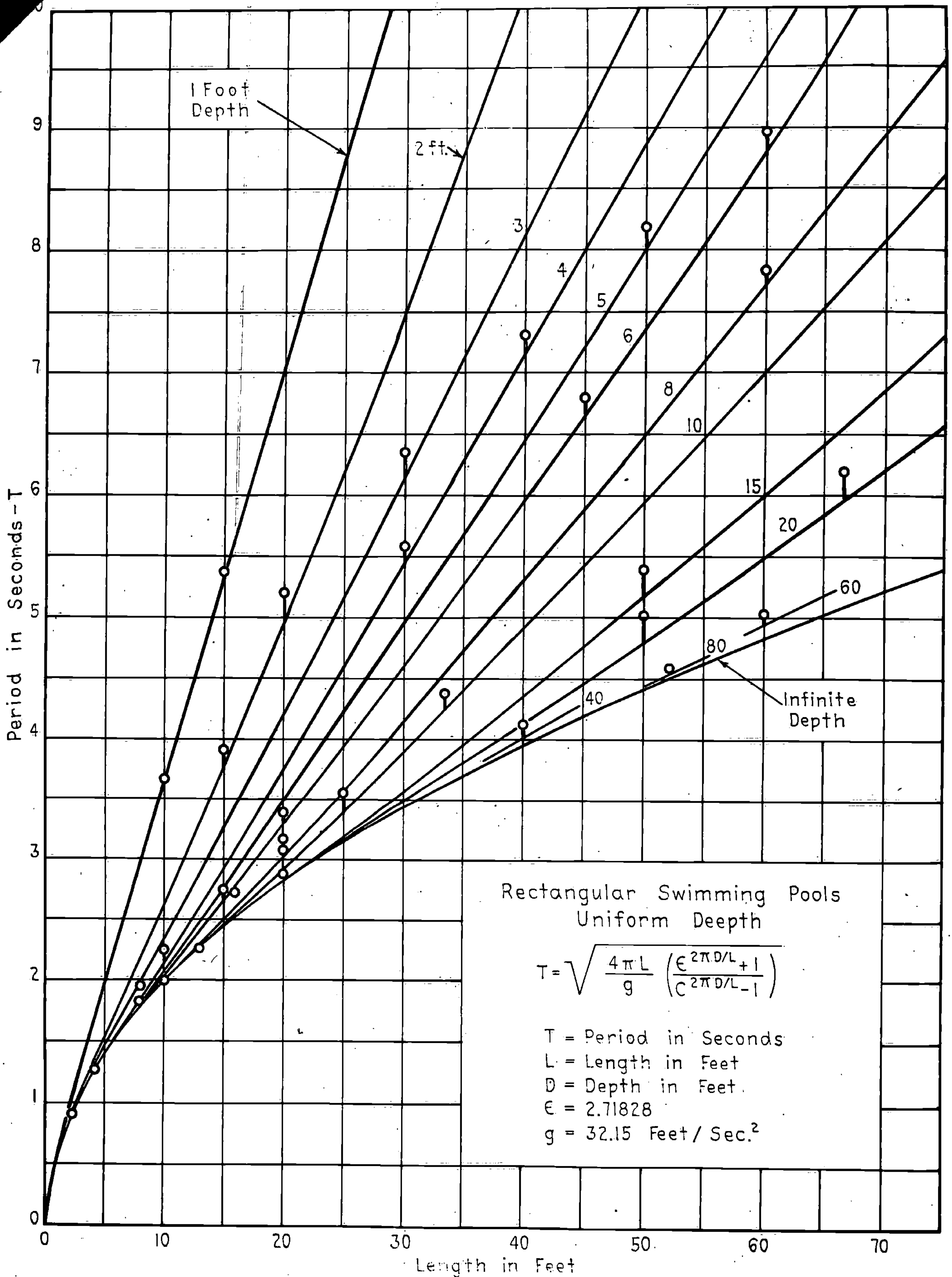
1.8
1.9
2.0


Effect of Flare in Regular Waves
Minimum Flare
Moderate "
Maximum "
Still Water Speed = 1.2 V/√L
Still Water Speed = 1.0 V/√L
Still Water Speed = .75 V/√L
Still Water Speed = 0.5 V/√L
Minimum Flare
Moderate Flare
Maximum Flare
Forward Speed of Ship in Head Seas
Wave length in Feet for Ship
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
200
400
600
800
1000
1200


Rolling Test of LST in Beam Seas
⊙-No Water in Hold.
All Other Conditions Have 2 Ft. Water in Hold.
□-3Ft. x 4Ft. Openings in Bhd. 1Ft. ϕ C.V.K.
▽-3Ft. x 6Ft. " " " 1Ft. ϕ C.V.K.
◇-3Ft. x 6Ft. " " " 1Ft. x 3 Ft.
Openings C.V.K.
△-3Ft. x 4Ft. Openings in Bhd. 1Ft. x 3 Ft.
Openings C.V.K.
Rolling Angle in Degrees
0
5
10
15
20
25
30
35
50
100
150
200
250
300
350
Wave length in Feet for Ship





Rectangular Swimming Pools
Uniform Deepth
T = √((4πL / g) ((ϵ^(2πD/L) + 1) / (C^(2πD/L) − 1)))
T = Period in Seconds
L = Length in Feet
D = Depth in Feet
ϵ = 2.71828
g = 32.15 Feet / Sec.²
1 Foot Depth
2 ft.
3
4
5
6
8
10
15
20
40
60
80
Infinite Depth
Period in Seconds - T
Length in Feet
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70