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INVESTIGATIONS OF PITCHING

by

Roger Brard

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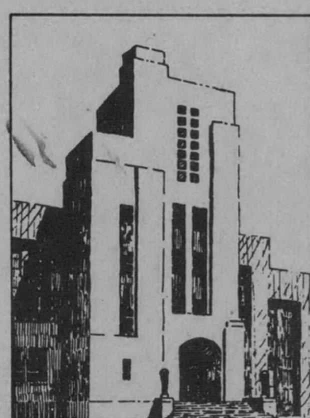

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INVESTIGATIONS OF PITCHING

(RECHERCHES SUR LE TANGAGE)

by

Roger Brard

Chief Engineer of the Corps of Naval Engineers
Director of the Paris Model Basin
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Paper presented at the Convention of the
Association Technique Maritime et Aeronautique
Session of June 1945

Translated by E.N. Labouvie, Ph.D.

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1. INTRODUCTION

These investigations are a continuation of those which were presented in 1939 in a paper by C. Igonet,* of the Corps of Naval Engineers.

In his work, Mr. Igonet demonstrated that the pitching motion on an ocean wave at zero speed can generally be determined in advance with sufficient accuracy by means of a rather rough method of calculation** of which we shall present the essential features. We assume θ to be the angle of pitch and t the time. By neglecting θ^2 before θ and $(\frac{d\theta}{dt})^2$ before $(\frac{d\theta}{dt})$ and by assuming, moreover, that there is no interference between heaving and pitching, the equation defining pitching is

$$J \frac{d^2\theta}{dt^2} + f \frac{d\theta}{dt} + P (R - a) \theta = T \cos \frac{2\pi t}{T_W}$$

The second term represents the pitching moment of the wave, the period of the latter being T_W. The amplitude T is calculated by assuming that the pressure at a given point in a fluid is due solely to the height of the water column above this point. Every dynamic effect is thus neglected. In this calculation, the inclination θ of the vessel and the slope of the sides (of the ship) are also neglected.

In the first term, the righting moment $P (R - a) \theta$ (P being the displacement of the vessel and (R - a) the modulus of longitudinal stability) does not give rise to any difficulty. $J\, d^2\theta/dt^2$ represents the moment of inertia, and $f\, d\theta/dt$ the moment of passive resistance. These two terms are determined by pitching experiments at zero speed in still water.

In the examples cited by Mr. Igonet, the described method is successful because the period of the wave is considerably greater than the natural period of the vessel.† Consequently, there is no effect of resonance, the motion is not very large, and the relative velocities of the vessel and of the fluid are small.

These circumstances—which justify the approximations agreed to—are not necessarily found in every pitching experiment at zero speed. They

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*"Pitching Experiments at Zero Speed," Bulletin of the Association Technique Maritime Aeronautique, 1939.

**Proposed by Weinblum (Werft Reederei Hafen of 1 October 1933).

†We shall write T_s' in place of T_s; T_s would then represent the theoretical period not taking into account the effects of water entrained by the vessel:

$T_s = 2\pi \sqrt{\frac{I}{P (R - a)}}$, I being the moment of inertia of the vessel alone in relation to its center of gravity.

are certainly not found in pitching experiments with the ship in motion when the ship surges upward (by meeting the wave at considerable velocity).

The period to be considered is, in effect, the visible period T_{W_a} of the wave. If the speed of the vessel increases, T_{W_a} decreases and may become smaller than T'_S. Besides, the moment of the wave, the moment of inertia, and the damping moment certainly depend on the speed of the vessel.

Our investigations have a double object: (1) to determine how the aspect of the motion is changed when synchronism can take place, and (2) to outline the bases of a theory capable of serving as a guide for a more thoroughgoing study.

Two kinds of results will be found below: Some will directly interest the user; for example, curves, etc., which give the amplitude of motion as a function of the running speed, and of the relationship Λ/L of the length of the wave to that of the vessel, both for a wave of given height. The delivery of documents of this sort to a commanding officer would specify what is advisable to observe at sea and it would facilitate the comparison between full-scale experiments and experiments on a model. The other results which cannot be directly exploited by the user are presented in such a manner as to permit the analysis of the motion of the vessel considered to be oscillating, and thus to establish a comparison between the pitching and the various vibratory motions encountered in a wide variety of technical fields.

2. TESTING EQUIPMENT

The experiments with waves in the large basin were carried out along the lines already reported by Mr. Igonet.* Certain improvements were introduced, however, in the former experimental set-up, both for the experiments on waves and for those in calm water.

For the tests on waves, a set-up was adopted which does not necessitate any interruption between the successive photographs of the ship; in this way, the eleven pictures are taken during the same period and not in the course of successive periods. Working over several periods, the improvement makes it possible to see whether the motion of the ship is really periodic. In fact, we observed that the forced motion is not built up instantaneously in spite of the considerable damping of the natural motion; moreover, it was seen that on account of the relative smallness of the basin, the disturbances brought about in the wave by the pitching of the model can completely change

*Cf. Igonet, loc. cit.

the aspect of the incident wave after a few oscillations and, as a consequence, change the motion of the pitching itself. The cameras were provided with a rapid driving device for the plates; the operation of the shutter by the wave-generator was perfected in such a way as to avoid every effect of inertia; and, in order that the eleven pictures might appear on the same plate, masking was used which reduces every view to what is essential, i.e., (1) the profile of the wave on the tank wall, and (2) the fixed graduated strips in front of which the reference marks on the model are displaced.

Figures 1 and 2 show the driving mechanism of the plate and the mechanism of the shutter. In Figure 3, a recording is reproduced.

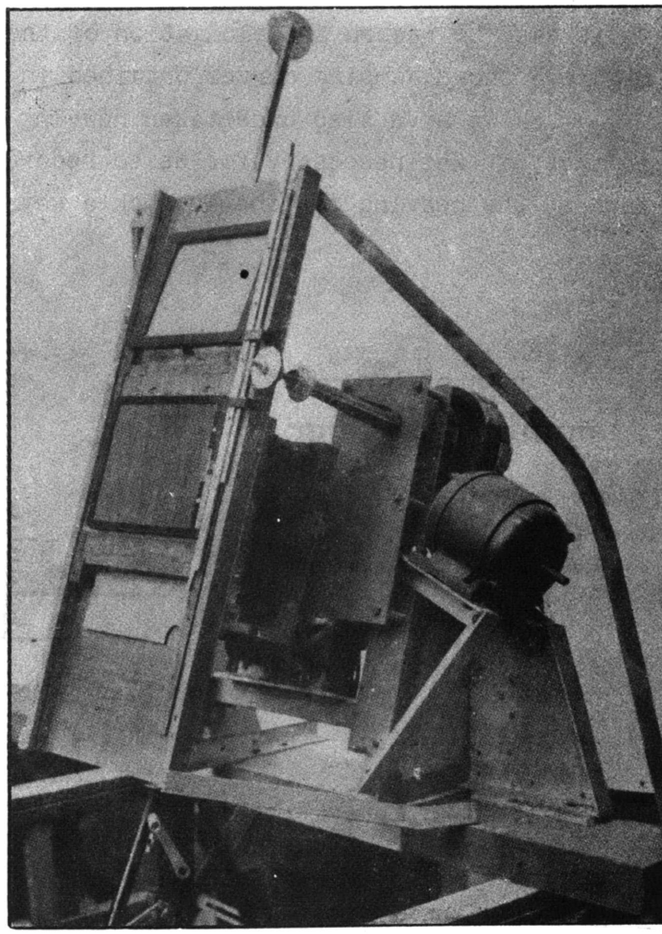

Figure 1

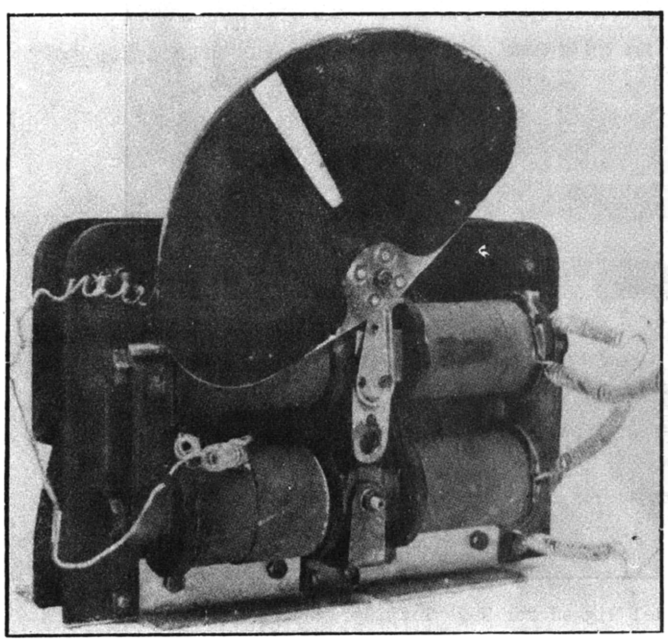

Figure 2

For the pitching tests in calm water, we were unable to make use of cinematography inasmuch as the circumstances did not make it possible to replace the cameras which had disappeared during the occupation of the laboratory by the German troops (June 1940 to February 1941). Therefore, we mounted two mercury-vapor lamps on the ship with flashes occurring every 0.01 second; two other lamps of a similar kind were mounted on a fixed stand (Figure 4a). So it is easy to record the elongation of the movement as a function of time. Figure 5 shows damping curves obtained in this way.

We have also undertaken heaving tests in calm water at zero speed. In fact, it was necessary for us to record the natural periods and the dampings of the heaving motions in such a way as to detect possible interference

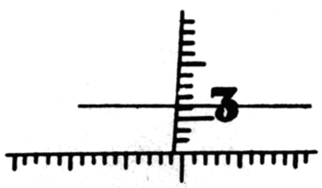

Figure 3a - Readings Made in Front of Model 5

(See also margin of Figure 4b)

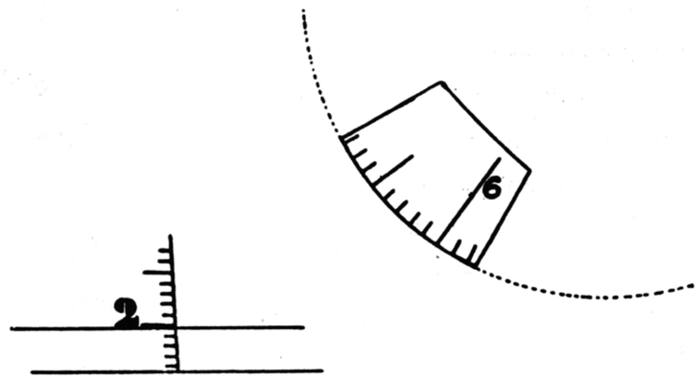

Figure 3b - Readings Made in Rear of Model 5

(See also margin of Figure 4b)

Figure 3

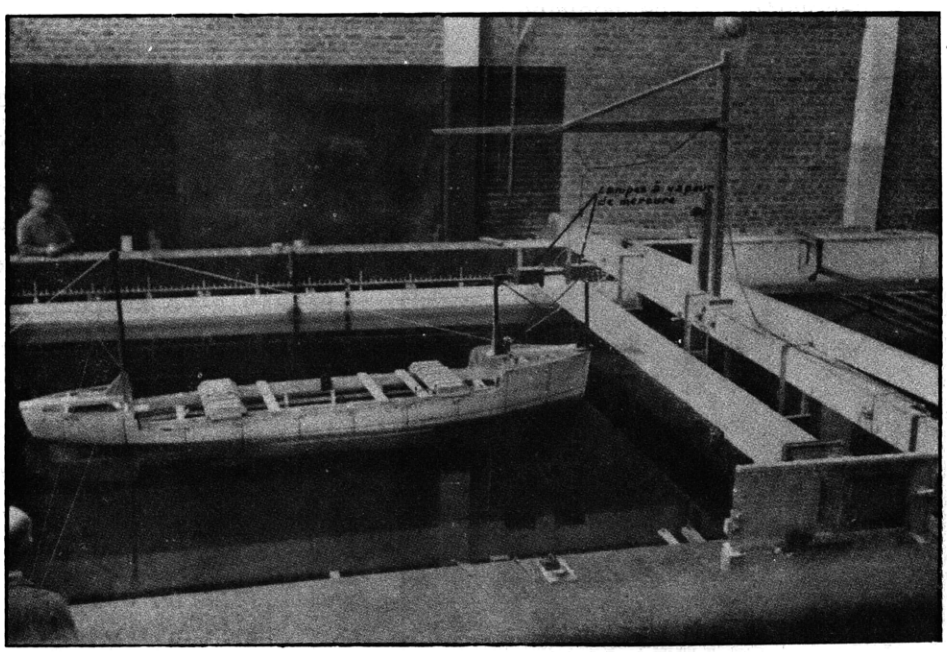

Figure 4a - Model Rigged for Wave Testing

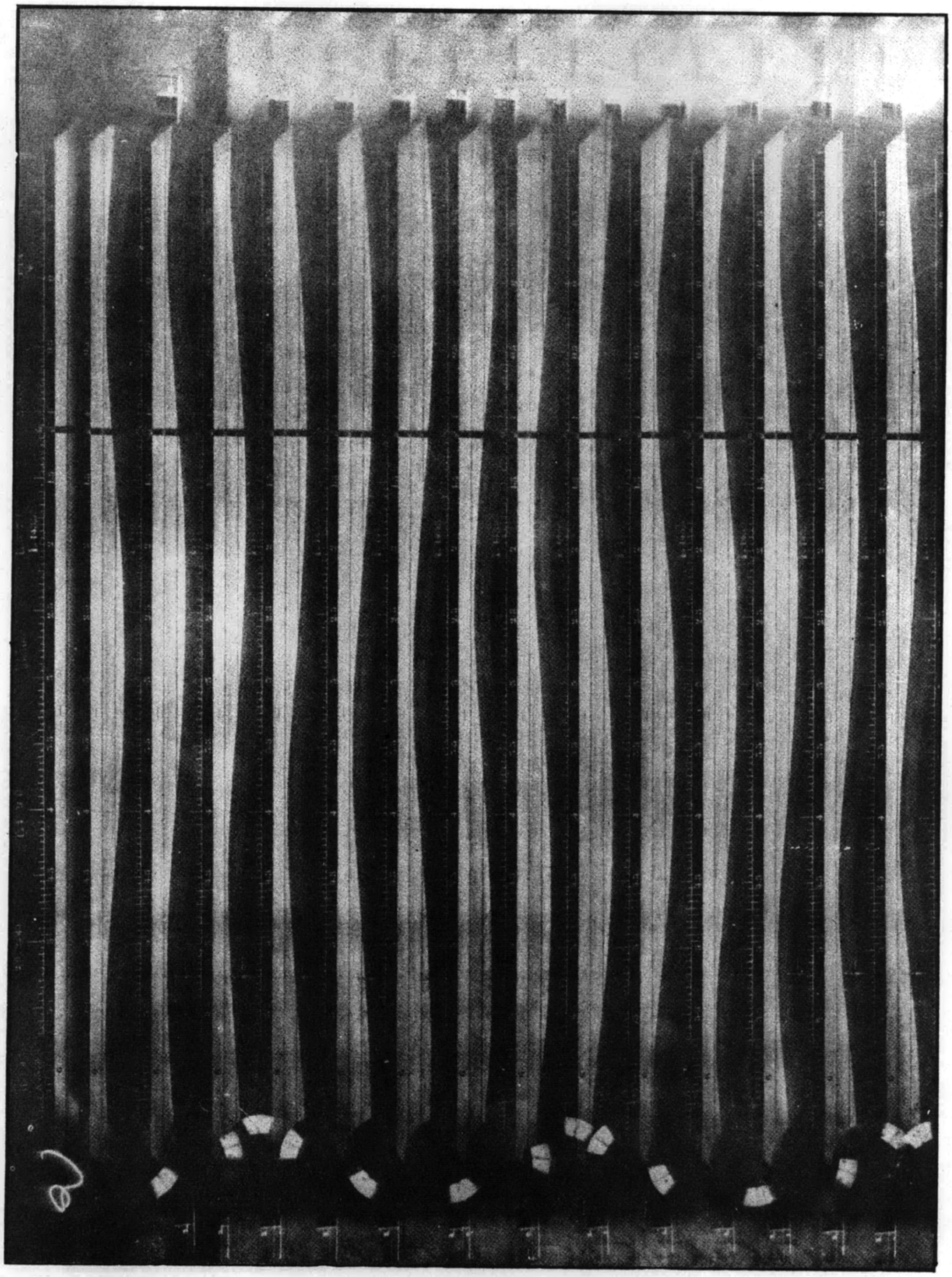

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Figure 4b - Photographs of Waves against Scale on Tank Wall

Figure 4

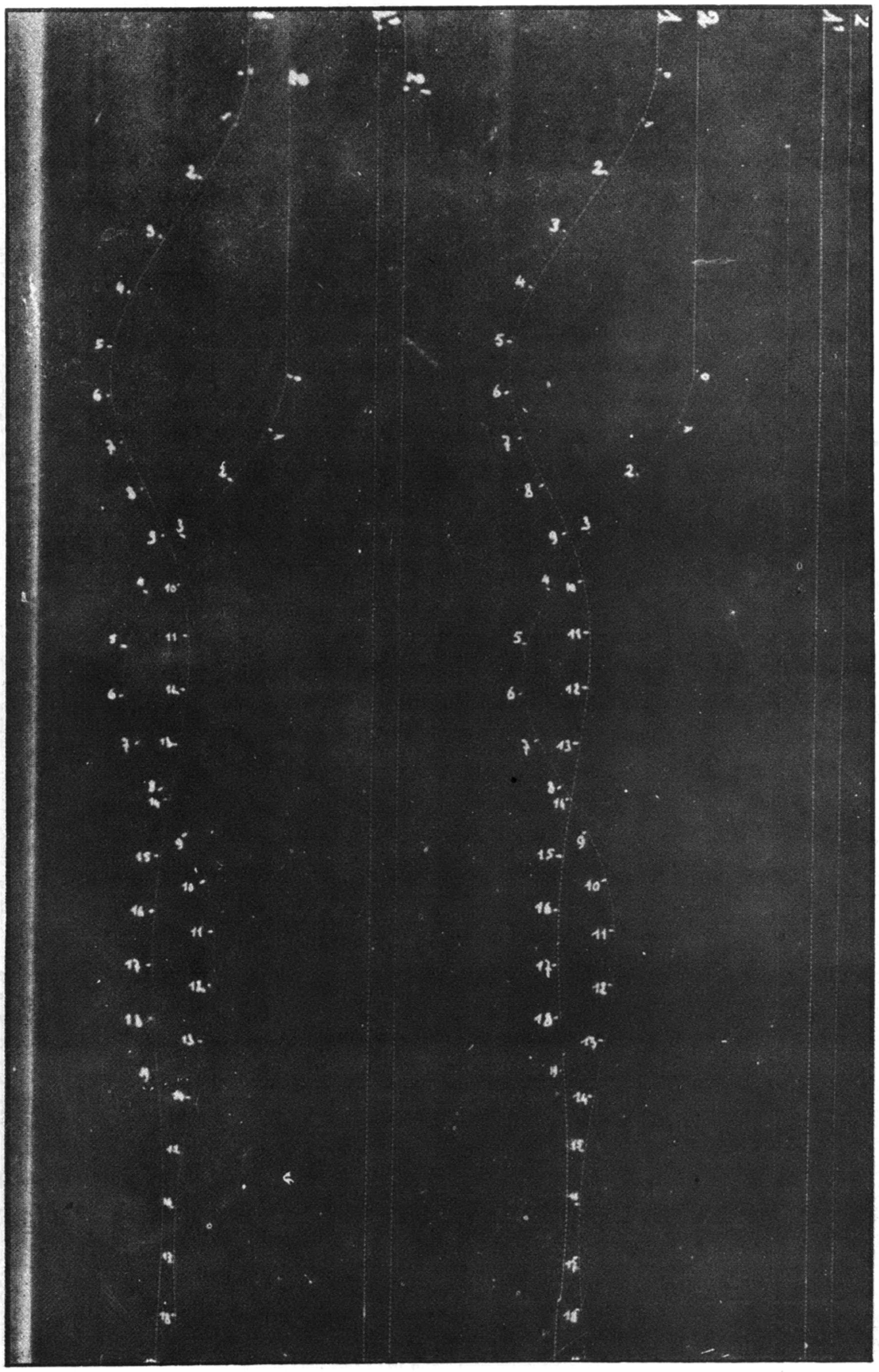

Figure 5

between heaving and pitching on the wave. Figure 6 indicates the arrangement. The results obtained were compared (cf. Figure 7) by starting with the draft of the model artificially deepened, and then by starting with the draft artificially decreased. Moreover, one does not discover any systematic difference, at least when the initial position differs rather little from the position of equilibrium (1/5 of the draft).

For the pitching of a ship going ahead we used a tank of 8 m by 1.33 m by 0.38 m. Instead of working with models about 6 m long, we had to work with very small models, of about 1.20 m. All these dimensions are obviously quite reduced, and one may fear scale effects as well as interaction between the model and the basin. However, the small wave basin made it possible to obtain a useful run proportionately very much higher than would have been possible in the large wave basin, and this by means of much less elaborate construction. Moreover, we were anxious to judge the importance of the scale effect by comparing the test results at zero speed on waves which were made under similar conditions in the small and in the large basin. Figure 8 shows that even if there is no identity of results, there exists between them enough similarity to make it reasonable to proceed with more extensive tests in the small basin.

The model-towing device was conceived by Mr. Igonet in 1939. By means of a small rod (cf. Figure 9), the model is connected to a carriage to which the testing speed is communicated. The rod allows the model, which is

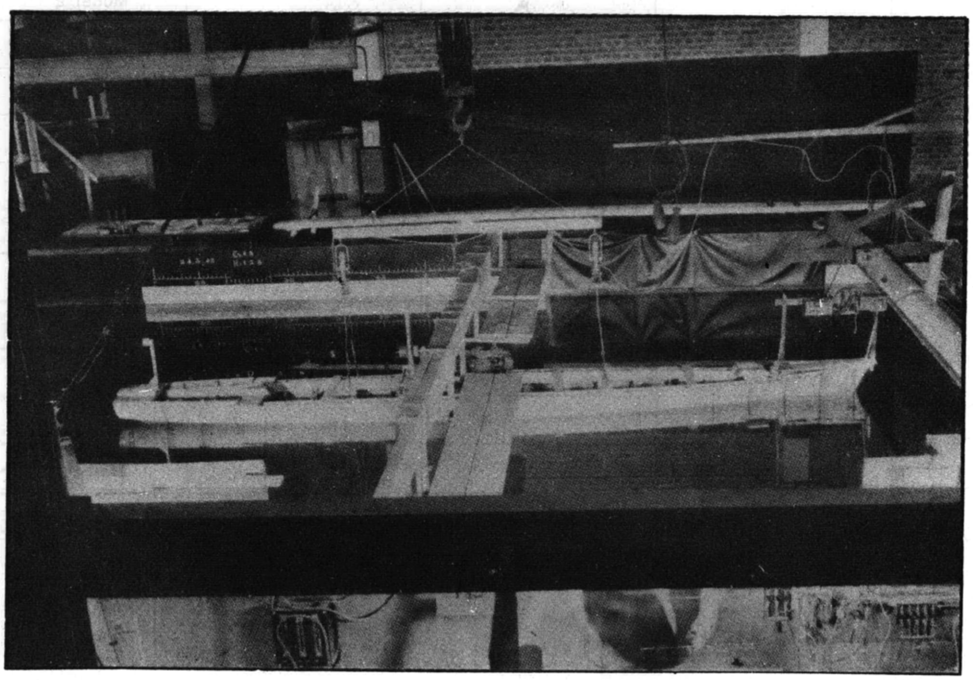

Figure 6

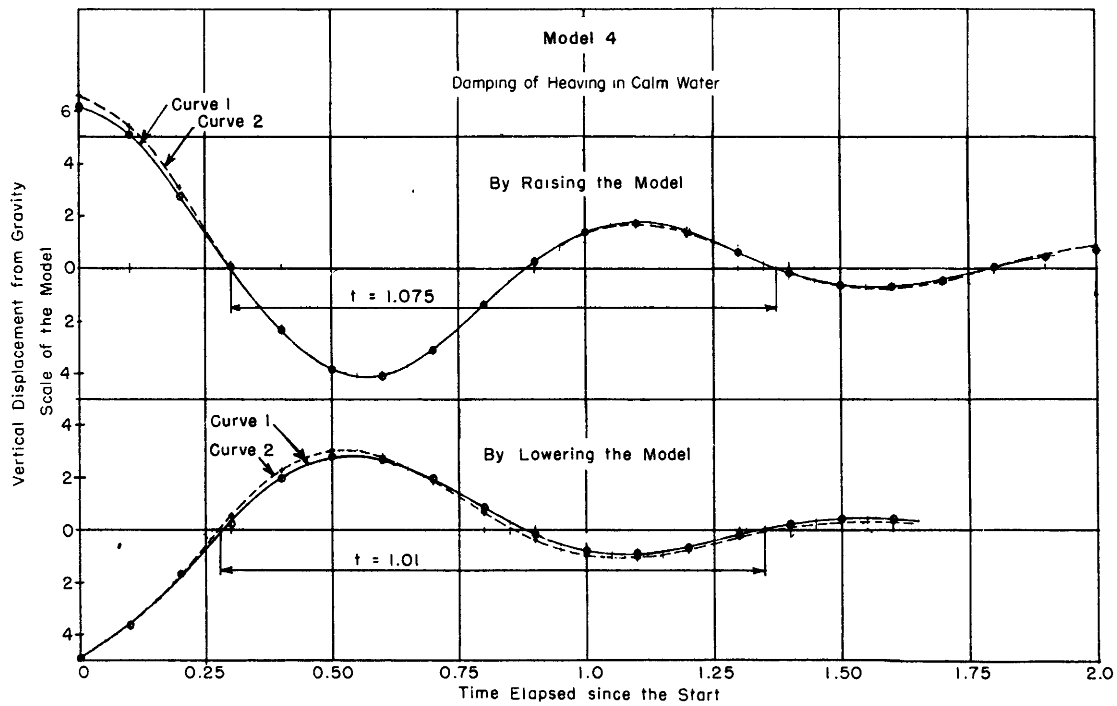

Figure 7 - Curves of the Values of Vertical Displacement of c.g. as a Function of Time

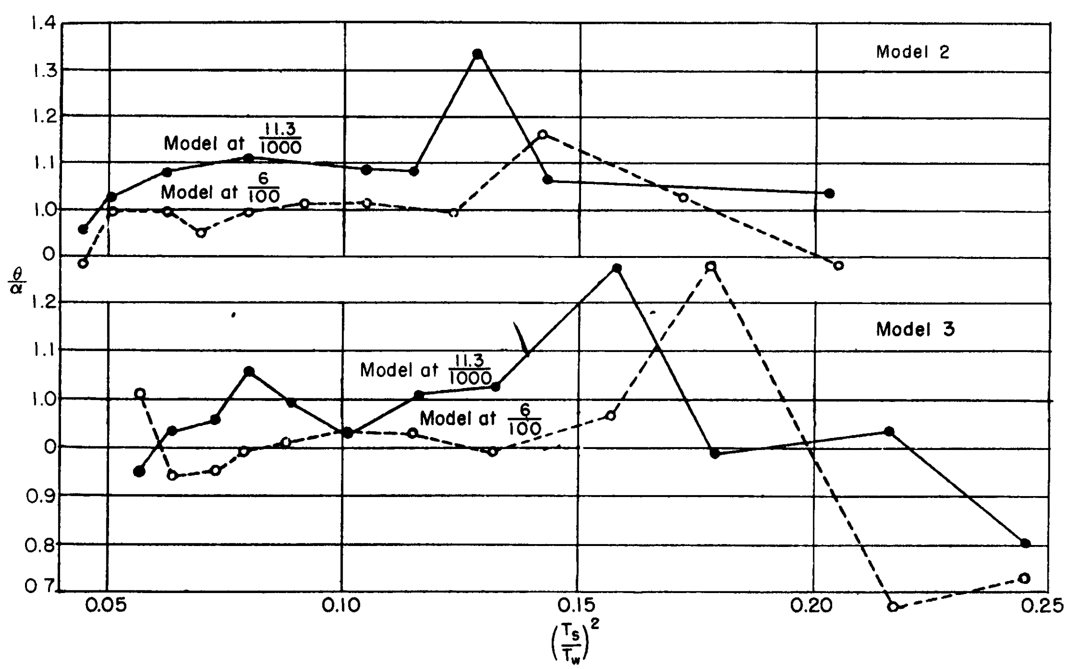

Figure 8 - Pitching at Zero Speed

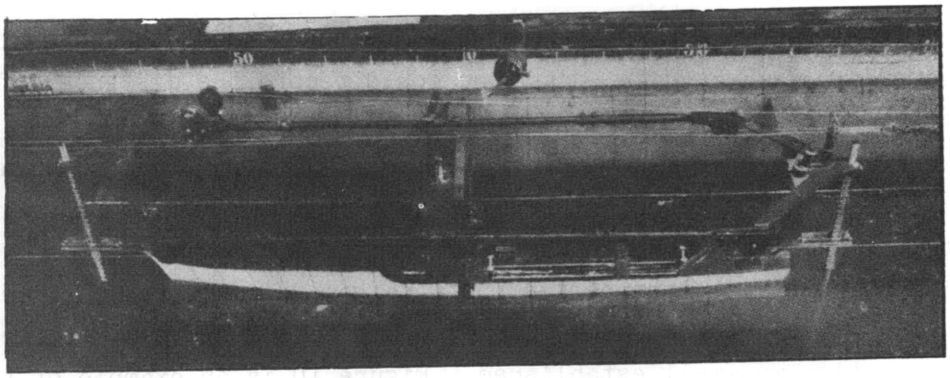

Figure 9

thus drawn at the desired speed, every freedom in its pitching and heaving motions. Let us point out, however, that this manner of attachment is not entirely satisfactory since it does not allow the model to follow the orbital motion of the wave.

The carriage is fitted with two calibrated bars which provide a sliding support for fork-shaped frames which are mounted in the front and rear of the models, and which make it possible to determine the trim θ and the height ζ of the center of gravity of the model.

The testing speed is transmitted to the carriage in the following manner: The latter is attached by means of an elastic cord to a tow rope wound on two reels which are located at the two ends of the tank, respectively. One of the two reels is fixed to the end of the shaft of a direct-current motor, the velocity of which is regulated by varying the power input. A preliminary calibration makes it possible to know approximately the voltage which corresponds to the running speed of the model to be arrived at. By varying the voltage around this approximate value and by measuring the corresponding model speeds, the required speed is finally arrived at by trial and error.

The measurement of the speed of the ship is made in a common enough manner: On a cylinder revolving at a constant speed, a recording pen registers the quarter-seconds while another pen records the distance traveled; the latter pen is controlled by a circuit which is closed when the model passes predetermined, regularly spaced points on the tank.

In the first series of tests, for each wave and each testing speed the model was photographed in ten different positions which were regularly out of phase with one another by one-tenth of a period. For this purpose, the direct-current motor which controls the movement of the carriage was started by means of an electrical contact carried by the drive shaft of the wave-generator paddle. During each run of the model, the angular position of this contact was shifted out of phase by 36° and the picture was taken when the model passed through (in) a point on the tank which was fixed once for all.

On each photograph appeared also the profile of the wave along the longitudinal wall of the tank; thus one could record the distance d from the crest of the wave to the center of gravity of the model.

Actually, in order to increase the accuracy of the recordings and to gain much time, the pictures were taken on a sliding plate following a procedure similar to that which was used for the large wave basin. We were content with fewer views per period, but the recordings were continued during about three successive periods. Thus it could be immediately verified whether the forced motion was well established. Figure 10 is an example of the results generally obtained.

3. PRECAUTIONS TO BE TAKEN IN ORDER TO OBTAIN RESONANCE CURVES

Since it is a question of an oscillator of one degree of freedom, the resonance curves are traced as abscissas with a function of the relationship between the natural period of the oscillator and the period of excitation and as ordinates with a function of the relationship between the semiamplitude of the motion and the elongation α which the application to the oscillator of a constant force equal to the semiamplitude of the exciting force would determine. For a nonlinear oscillator, there are as many curves as there are values of α. The test results of a nonlinear oscillator are represented by a cluster of curves depending on the parameter α, the axis of the abscissas constituting a scale T_S/T_{W_a} and the axis of the ordinates a scale θ/α.

It is necessary to take into account the field of disturbance occasioned by the motion of the ship.* This field is not the same for a ship that is motionless or in motion—if one prevents it from pitching or lets it move freely.

Various theoretical considerations have shown that the coefficients of the equations of pitching motion are the functions of the parameter $\gamma = 2\pi V/g\ T_{W_a}$, which is dimensionless and which one could therefore consider as the relationship between the speed of the ship and the swiftness of a wave, the true period of which would be equal to T_{W_a}.

These same considerations show, moreover, that, if $\gamma < 1/4$, the waves produced by the ship spread over the entire free surface of the sea such as happens at zero speed ($\gamma = 0$). On the other hand, for $\gamma > 1/4$, the waves produced by the ship are concentrated in a V-shaped area similar to that of the accompanying waves. The theory makes it possible, therefore, to

*We have partially described its effects on the rolling in calm water in our paper of 1939.

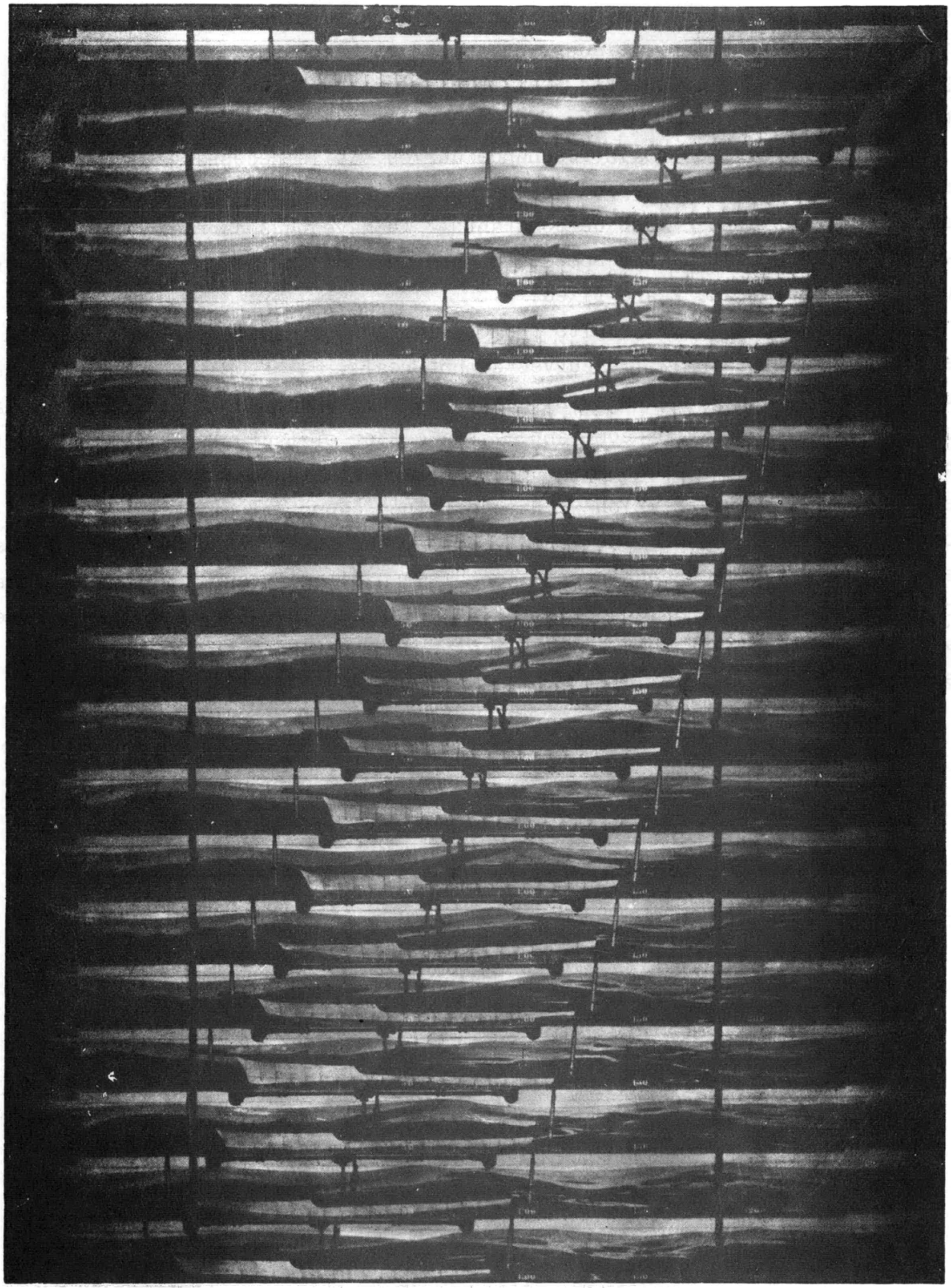

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Figure 10

foresee that the pitching motions for $\gamma \gg 1/4$ and for $\gamma \ll 1/4$ must differ greatly. In particular, it does not appear to be possible to extend to appreciable running speeds the results obtained during a wave test at zero speed.

In order to obtain resonance curves, it is necessary that the various points of the curve depend on the abscissas only and that consequently not only α, but also γ must be constants. We have thus carried out most of our tests by regulating the speed, the period, and the height of the wave in such a way that α and γ are fixed.

A complication results from the motion of heaving if the latter reacts to the pitching: The curves cannot really be resonance curves if the coefficient β— which for heaving plays the role which the coefficient α plays for pitching—is not kept constant. As a matter of fact, it is impossible to satisfy the three conditions α = constant, γ = constant, β = constant and, as a result, the curves which we have obtained cannot be exactly resonance curves. Moreover, as will be seen later on, the test results do not obviously demonstrate any pronounced interaction between pitching and heaving. It does not seem, therefore,—at least at the stage of our investigation at which we have arrived thus far—that the difficulty here referred to is extremely serious.

4. CHARACTERISTICS OF THE MODELS TESTED

Model	1	2	3	4
L = Length of flotation	28.30 m	100 m	100 m	100 m
l = Width of flotation	6.176 m	11.42 m	9.95 m	11.40 m
p = Depth of hull	2.974 m	3.32 m	3.55 m	3.36 m
B^2 = Immersed surface of the midship frame	13.203 m^2	29.14 m^2	26.86 m^2	29.25 m^2
W = Displacement in m^3	241.533 m^3	1750.303 m^3	1602.490 m^3	1809.765 m^3
R = a	23.905 m	255.31 m	262.34 m	259.28 m
Il = Mass inertia (M.T.)	1151	117.169	113.104	127.849
$B = \frac{B^2}{l \times p}$	0.719	0.768	0.759	0.763
$\delta = \frac{W}{L \times l \times p}$	0.465	0.461	0.443	0.472
ϕ total $= \frac{W}{B^2 \times L}$	0.646	0.601	0.597	0.619
$\psi = \frac{1000W}{L^3}$	10.657	1.750	1.603	1.810
S = Surface of flotation	131.61 m^2	832.18 m^2	754.44 m^2	829.94 m^2
I_s = Inertia of the surface of flotation ($m^2 \times m^2$)	5976	451.665	423.792	474.508
$\frac{W}{S \times p}$ (total)	0.617	0.633	0.598	0.649
$\frac{W}{S \times p}$ (bow)	0.634	0.688	0.648	0.705
$\frac{W}{S \times p}$ (stern)	0.603	0.591	0.562	0.605

<table>
<tr><th colspan="5">Tests Made</th></tr>
<tr><td rowspan="2">Tests Carried Out</td><td>Model at 1/7
Large Wave Basin
Pitching at Zero Speed
(30m × 7m × 2.40m)
2.63 m ≦ Λ ≦ 13.32 m
0.080m ≦ H ≦ 0.175m</td><td colspan="3">Models at 6/100

Pitching at Zero Speed</td></tr>
<tr><td></td><td>4.65 m ≦ Λ ≦ 15.80 m
0.122m ≦ H ≦ 0.224m</td><td>4.90 m ≦ Λ ≦ 15.80 m
0.115m ≦ H ≦ 0.280m</td><td>4.65 m ≦ Λ ≦ 5.80 m
0.124m ≦ H ≦ 0.247m</td></tr>
<tr><td></td><td>Small Wave Basin
(8m × 1.33m × 0.38m)</td><td colspan="3">Models at 11.3/1000

Pitching at Zero Speed and Underway</td></tr>
<tr><td></td><td></td><td>0.87 m ≦ Λ ≦ 2.57 m
0.023m ≦ H ≦ 0.042m</td><td>0.92 m ≦ Λ ≦ 2.57 m
0.022m ≦ H ≦ 0.053m</td><td>0.87 m ≦ Λ ≦ 2.57 m
0.023m ≦ H ≦ 0.046m</td></tr>
</table>

5. RESULTS EXAMINED FOR PRACTICAL APPLICATION

Given below (Figures 11, 12, 13) are the curves which represent—for Models 2, 3, and 4, respectively—the variations of the amplitude θ of the pitching motion as a function of the running speed, the height of the wave amounting to 3.33 m; the ratio Λ/L, constant along the entire length of one curve, varies from 0.8 to 2.2.

These curves are sufficient to show how much the speed influences the pitching. The maximum values of θ of a ship underway are generally much higher than at zero speed. For the small values of Λ/L, θ begins to decrease when V increases; then θ increases (and even vertically almost for Λ/L of the order 1.1); then θ remains constant—or at least within rather narrow limits—for a rather extended range of speeds; finally, θ decreases rather rapidly. For average or large values of Λ/L, θ begins by increasing rather progressively, the maximum—which corresponds to higher and higher running speeds—being of the same order as the one observed for smaller values of Λ/L. Finally, for the very large values of Λ/L, the variations of θ are much less considerable, the maximum observed being not very much greater than the amplitude recorded at zero speed.

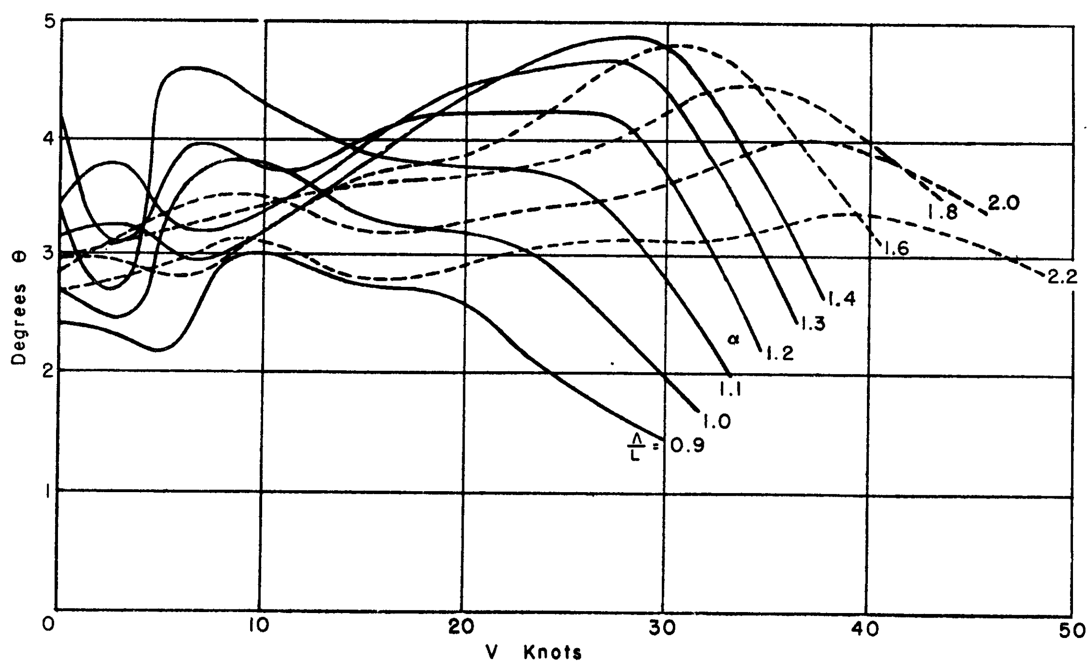


Figure 11 - Model 2, Pitching of a Ship Underway

Curves of the values of the maximum angle of pitch θ as a function of the running speed V for a wave height of 3.33 m.

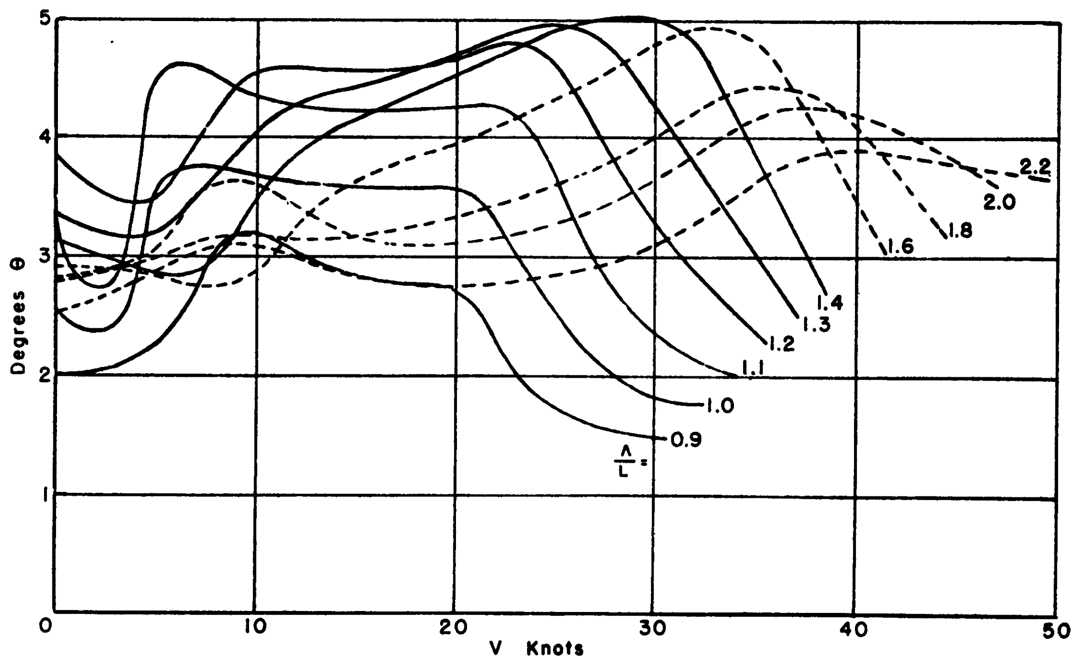


Figure 12 - Model 3, Pitching of a Ship Underway

Curves of the values of the maximum angle of pitch θ as a function of the running speed V for a wave height of 3.33 m.

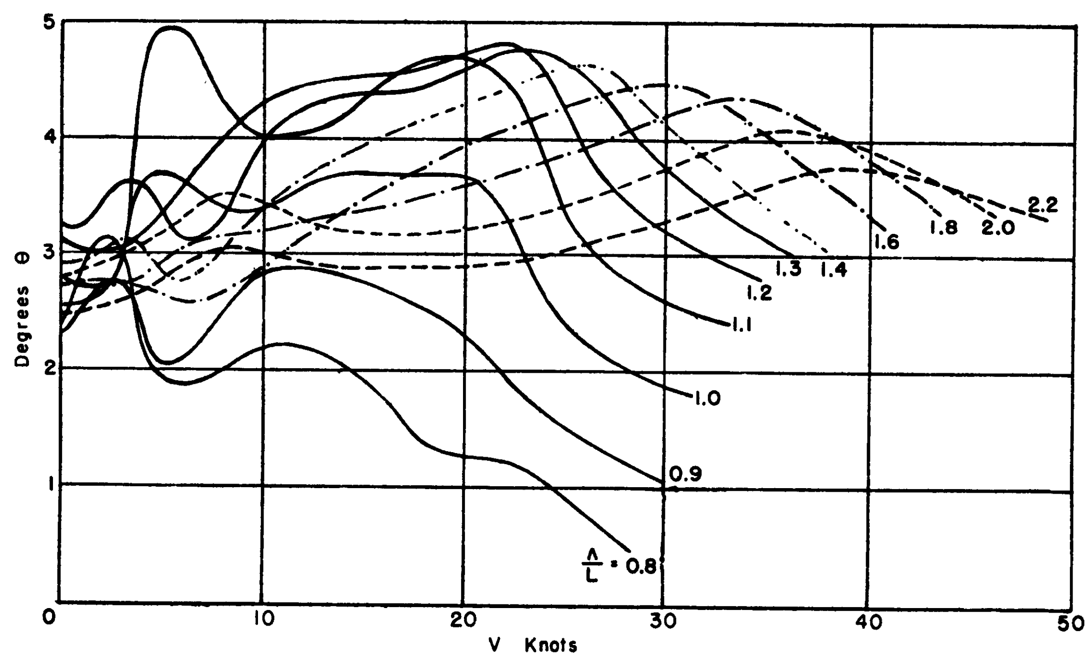


Figure 13 - Model 4, Pitching of a Ship Underway

Curves of the values of the maximum angle of pitch θ as a function of the running speed V for a wave height of 3.33 m.

The curves produced here would make it possible to give accurate instructions to ship captains on the advantages—as to behavior in a seaway—to be derived from a variation of the running speed. Their accuracy would be easy to control, by the way.

Model 1, in keeping with its purpose, was made the object of tests at zero speed only. Figure 14 represents the variations of $\theta L/H$ as a function of Λ/L. Figure 15, which will be analyzed in the following section, is likewise particularly simple to use because the maximum angle of pitch is read directly by interpolation inasmuch as the wave length (or the period of the wave) is in abscissas and the height in ordinates. This figure shows that this model reaches its maximum amplitude for a length of wave of 23 m, or $\Lambda/L = 0.81$.

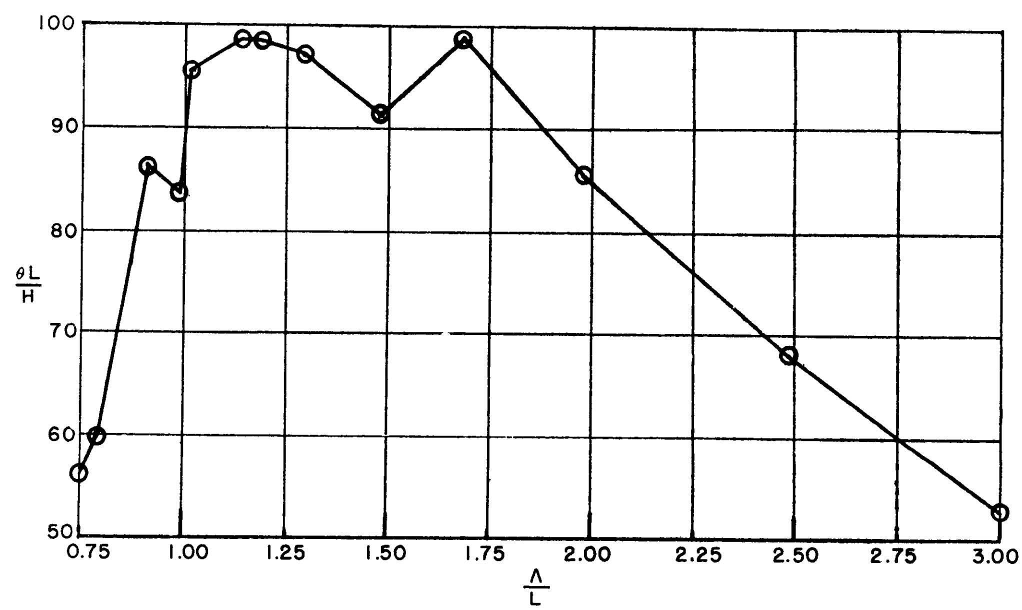


Figure 14 - Model 1, Pitching at Zero Speed

6. EXAMINATION OF THE TEST RESULTS FROM THE THEORETICAL STANDPOINT

PITCHING AT ZERO SPEED ON A WAVE

Figure 15, which sums up the test results relating to Model 1, was set up in the following manner: In abscissas are stated the periods of the wave for the model and the full-scale structure as well as the length of the wave (for the full-scale structure); in ordinates are stated the heights of the wave (for model and the full-scale structure). Next to each of the points representing a pair of values—period, height of wave—for which a test was made, the value of the maximum angle of pitch θ was noted. We then plotted—in form of a solid line—and after balancing the points, the curves corresponding to maximum angles of pitch which were constant and equal to 2°, 2.5°, 3°, 3.5°, 4°, 4.5°, and 5°, respectively. In the form of a dotted line are traced the curves with angles of pitch that are constant and equal to 2°, 3°, and 4°, respectively, obtained by the rough method of calculation pointed out in the Introduction. It is seen that the curves θ = constant and α = constant are very closely related (if the values of the constants are equal) when the period of the wave is sufficiently long; the ship is then set in motion by a movement of forced pitching which is hardly influenced by phenomena of inertia. On the other hand, for sufficiently short waves, the curves θ = constant deviate considerably from the curves α = constant; they become hollow toward the regions which correspond to values of θ that are clearly below those of α.

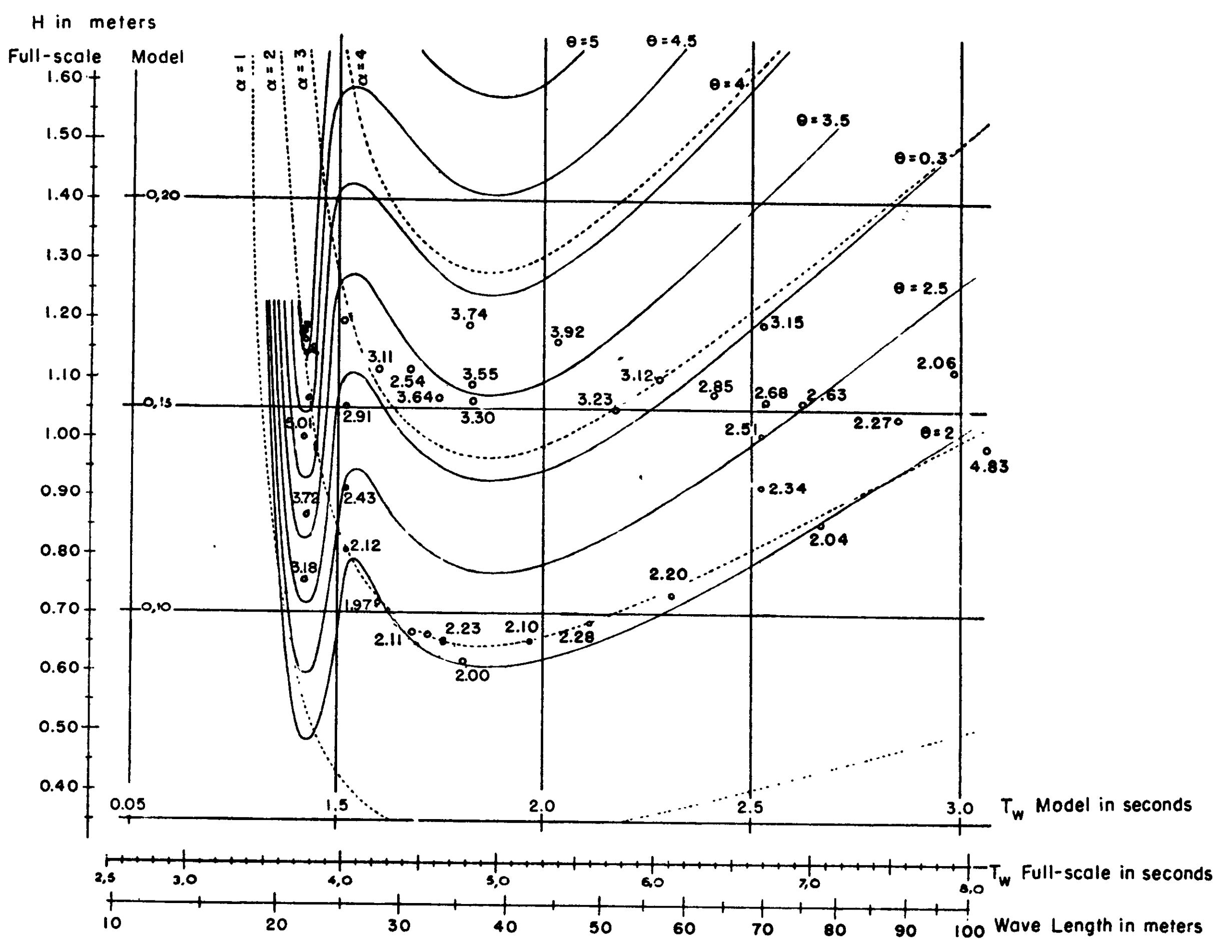
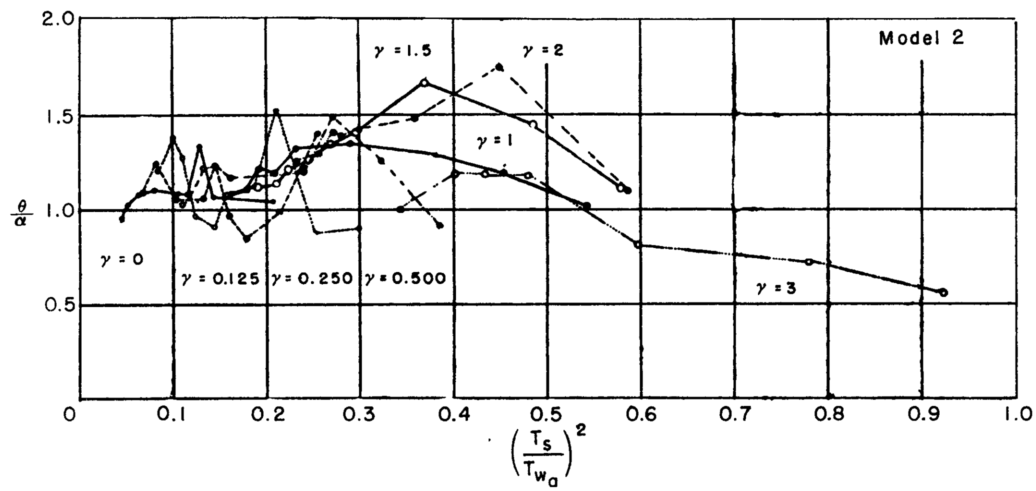


Figure 15 - Pitching at Zero Speed

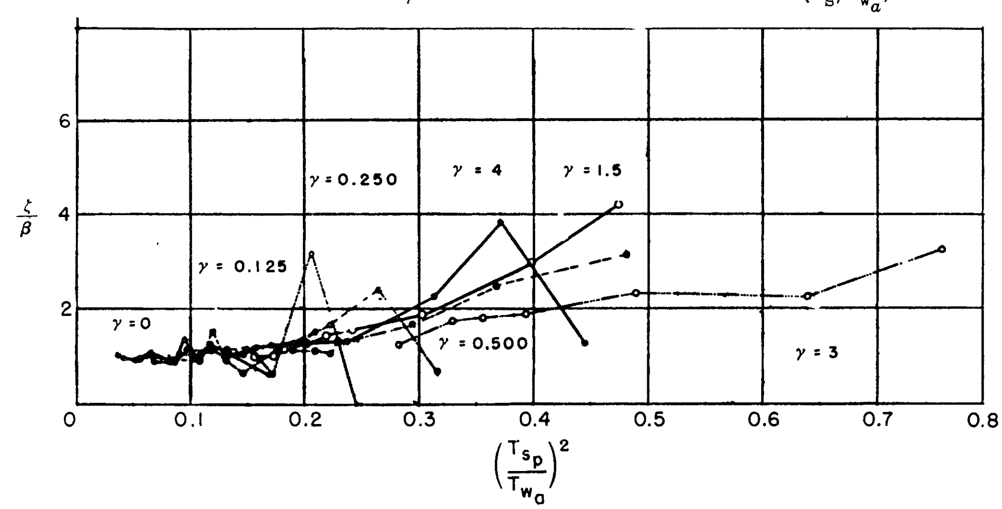
Here is where the resonance between the ship and the wave manifests itself; a small wave may call forth very large oscillations. Finally, for very short waves, the curves θ = constant and α = constant tend to merge again (if the two constants have the same values); the synchronism no longer takes place.*

PITCHING OF A SHIP UNDERWAY

Figure 16, 17, and 18 represent for Models 2, 3, and 4 the variations of θ/α and ζ/β as functions of $(T_s/T_{W_a})^2$ and $(T_{s_p}/T_{W_a})^2$, ζ being the semiamplitude of the heaving, β the coefficient already defined, and T_s and



Curves of the Values of θ/α as a Function of the Values of $(T_s/T_{W_a})^2$



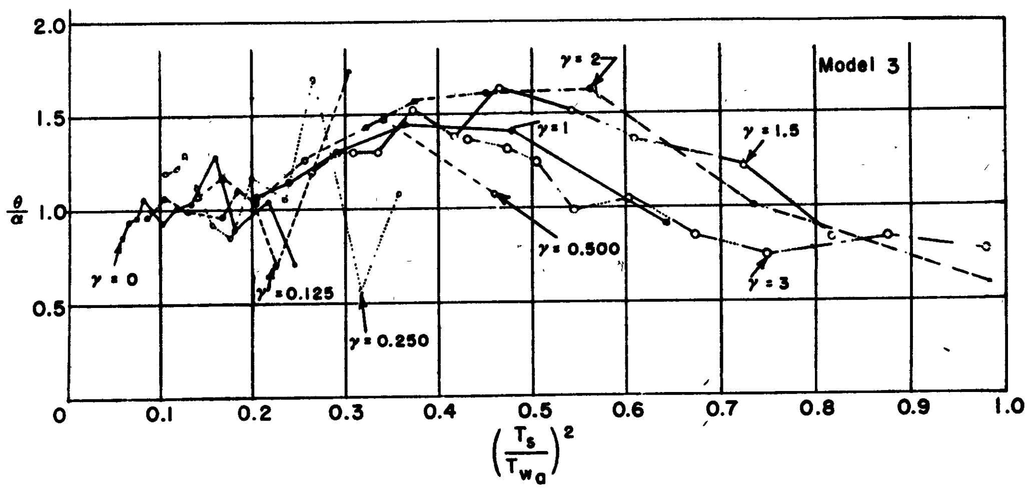
Curves of the Values of ζ/β as a Function of the Values of $(T_{s_p}/T_{W_a})^2$

Figure 16

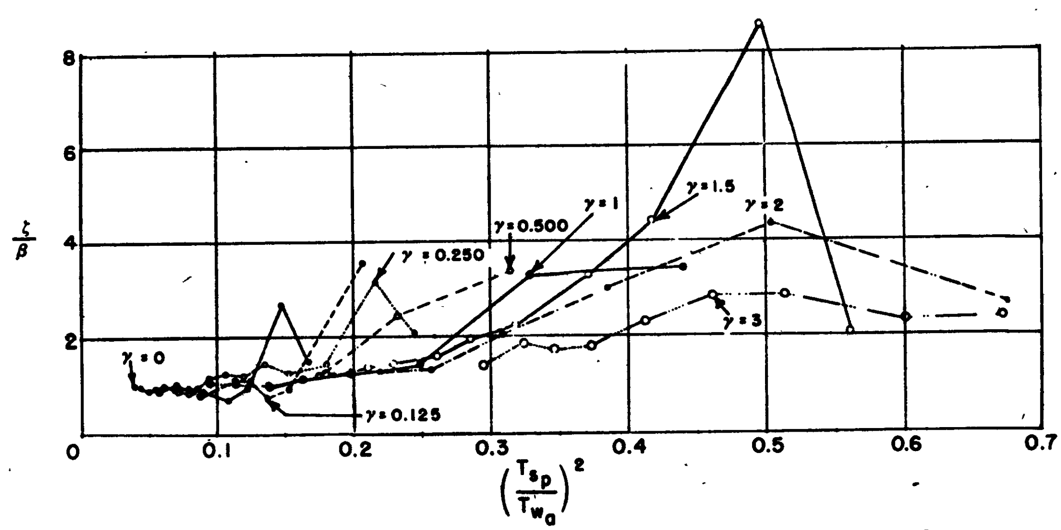
*Figure 15 shows the phenomenon in a striking manner. The idea of this sort of representation was conceived by M. Aupetit, an engineer of the Corps of Naval Engineers employed at the Paris Model Basin.

T_{s_p} the theoretical periods of pitching and heaving (not taking into account the "entrained water" of the model). The scales of the abscissas are arranged in such a way that the points located on the same return line correspond to the same test.

We do not judge it to be useful to connect the experimental points by continuous lines because we do not know whether or not the irregularities which they manifest are due to imperfections in the apparatus. The measurements are nevertheless sufficiently accurate so that one may be sure that these irregularities are not due to recording errors. However, the various following reasons could entail systematic deviations:



Curves of the Values of θ/α as a Function of the Values of $(T_s/T_{w_a})^2$

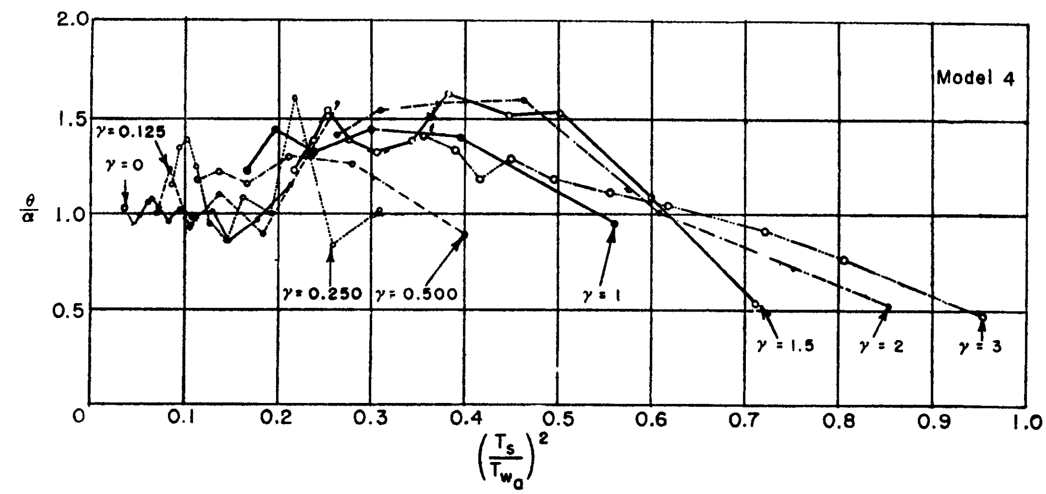


Curves of the Values of ζ/β as a Function of the Values of $(T_{s_p}/T_{w_a})^2$

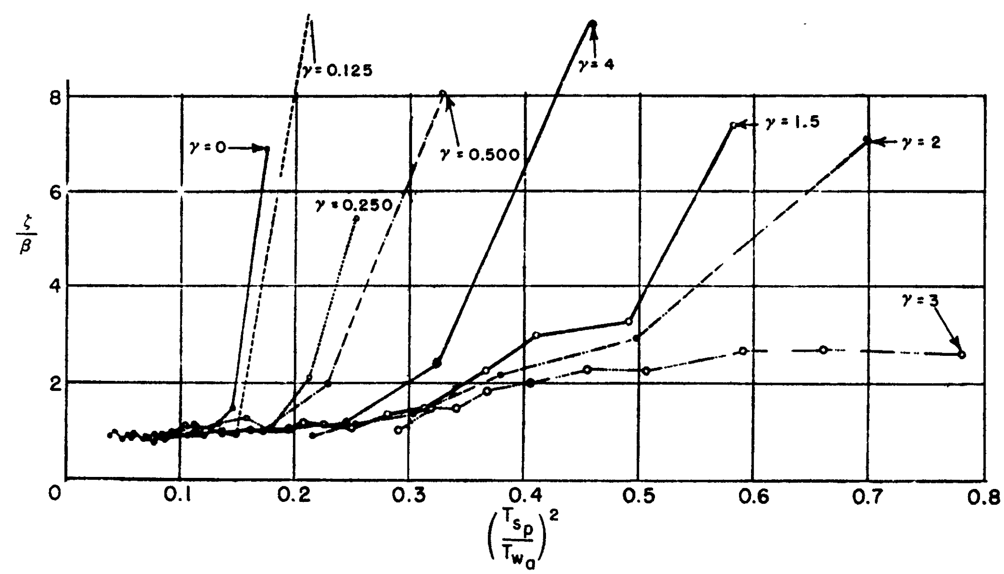
Figure 17

First, in order to maintain α constant (or β), we had to vary the height of the wave, the greatest differences of level (contouring) corresponding generally to the shortest waves. It follows that we were not always working under the best conditions for utilizing the basin, and that the accuracy of the wave produced has certainly suffered as a result, especially in the right hand portions of the curves.

Second, because of the smallness of the basin, it happened under certain circumstances that the waves produced by the model react anew on the latter after reflection from the lateral walls of the basin.



Curves of the Values of θ/α as a Function of the Values of $(T_s/T_{w_a})^2$



Curves of the Values of ζ/β as a Function of the Values of $(T_{s_p}/T_{w_a})^2$

Figure 18

Third, the calculation of α (and of β) comprises approximations itself, the effects of which become already obvious at zero speed in the form of disagreements between the calculated and the measured pitching (these disagreements are considerable for the small values of Λ/L and so for the large values of $(T_S/T_W)^2$*).

Fourth, the existence of inter-action between pitching and heaving.

At present, it is quite difficult for us to indicate which one of these causes plays the most important role. Figures 16, 17, and 18, and other considerations also, suggest to us that heaving affects pitching only slightly, even though the natural periods of pitching and heaving are relatively similar. The effect of the other causes can be roughly estimated by the zigzags of the curves $\gamma = 0$. For $\gamma = 0$, in fact, the curves of θ/α and ζ should be practically identical with the straight lines $\theta/\alpha = 1$, $\zeta/\beta = 1$ for the three models under discussion (one is then quite far from synchronism); in reality, they oscillate irregularly about these two straight lines.

If one disregards the irregularities of the order of those which one observes in the case where $\gamma = 0$, one concludes that on the whole the curves have a different trend—according to whether $\gamma \gg 1/4$ or $\gamma \ll 1/4$. For $\gamma \gg 1/4$, the curves roughly resemble classical resonance curves. They present a very definite maximum, but (one) with a curvature that is little accentuated because of the great damping. For $\gamma < 1/4$, they seem to possess two maxima which are not so high and are much more pointed than in the preceding case.

The supposition that these different maxima would correspond to resonances, and consequently to $T_{W_a} = T_S$, involves this conclusion: That the inertia resulting from the field of disturbance varies considerably with γ. Figure 19 shows the variations. The values of J/I thus determined for $\gamma \gg 1/4$ and those which, for $\gamma < 1/4$, correspond to the maximum on the right of the curves in θ/β, seem to coincide. It is to be noted that the inertia increase resulting from the field of disturbance for the very large values of γ appears to tend toward that value which the measurement of the period in the damping motion in calm water assigns to it. This phenomenon is not so strange; on the contrary, it seems to constitute a verification of the theoretical conceptions which, as mentioned above, led us to introduce the coefficient γ. In the pitching test in calm water, in fact, the ship encounters "new water," as Bertin expressed it, i.e., water which is not yet disturbed in any appreciable manner; it is the same thing during pitching on a wave when the running speed is very high.

*Cf. Igonet, loc. cit., Figure 7, p. 279.

Our tests hardly permit us to make any significant observations on the phases of heaving and pitching. Nevertheless, they do enable us to indicate how the average position of the instantaneous (actual) center of rotation varies with γ (Figure 20a). The latter describes a curve (Figure 20b) which presents infinite branches because θ and ζ do not cancel simultaneously; we took as average position of the instantaneous center the meeting point of the asymptotes.

7. CONCLUSIONS

The study, which we have just reported briefly, represents merely a first stage in an investigation which proves extremely difficult both from the theoretical and experimental point of view. Many efforts will still have to be made before the various uncertainties mentioned in Section 6 can be resolved and before we shall be able to link in a coherent fashion the qualities

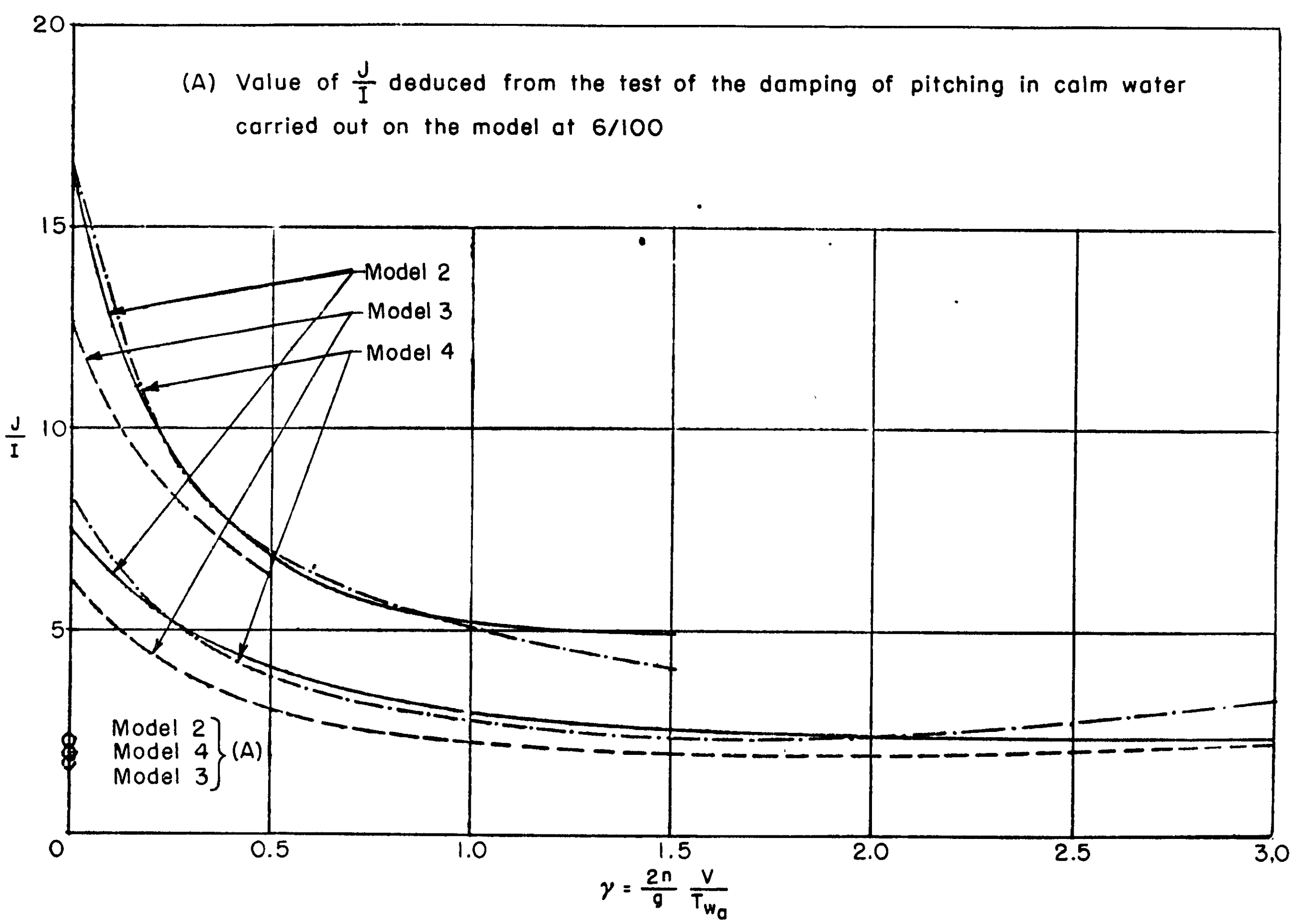


Figure 19 - Curves of the Value of J/I Corresponding to the Maximum Angles of Pitch as a Function of the Values of γ

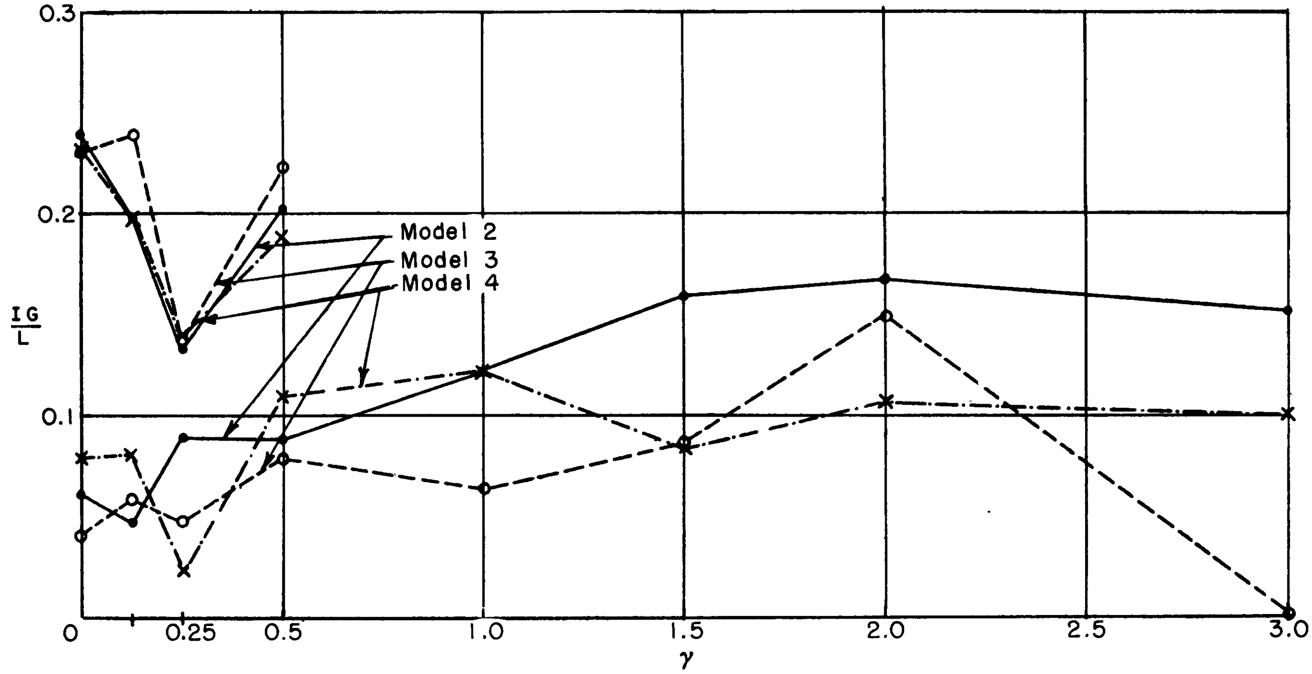


Figure 20a - Values of IG/L as a Function of the Values of γ

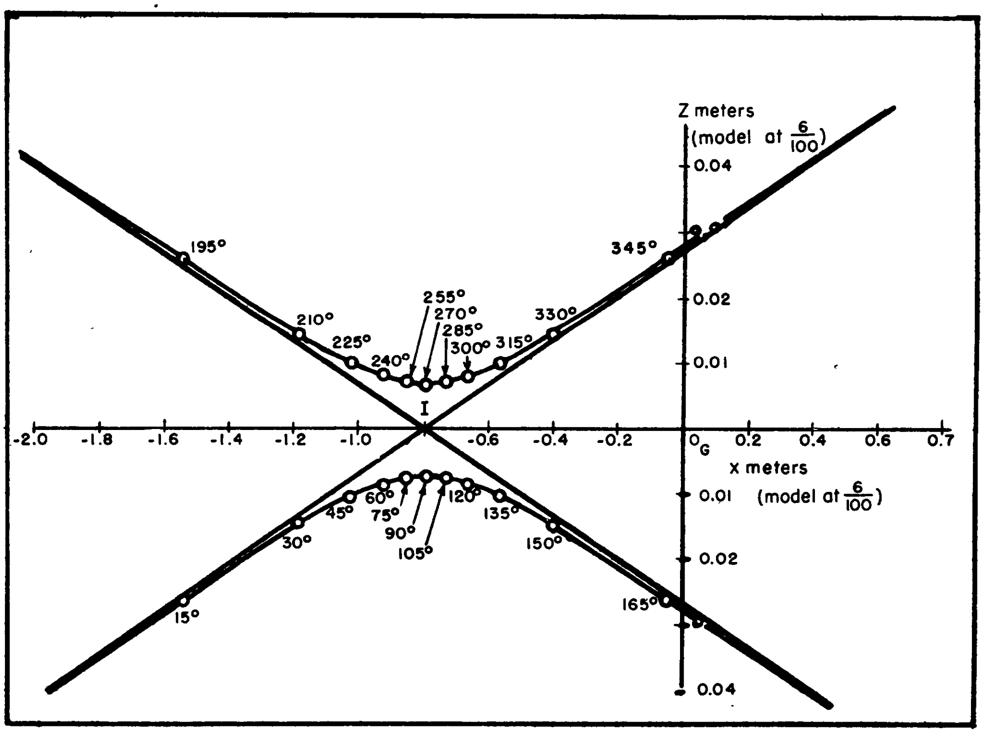


Figure 20b

Figure 20

of behavior during pitching and the coefficients characterizing the ship forms.

Our tests confirm, however, that the manner in which a ship behaves underway could not be foreseen from the results of calculations or from tests relating to zero speed. Not all conjecture is impossible, however: When proceeding directly to pitching tests on a vessel underway, the Model Basin is in a position to give the authors of projects the necessary information.

These tests indicate, furthermore, that for certain ships (tow boats and trawlers, etc.), it is wise to study on the model itself the pitching at zero speed; the possibility of the resonance excludes the use of the Weinblum method.

Finally, they draw attention to the usefulness of introducing into the phenomena accompanying the motion of a ship on the regular wave a parameter playing a role which is rather similar to that played by the Mach-Sarrau number in the case of the flow of compressible fluids.