UNITED STATES EXPERIMENTAL MODEL BASIN

NAVY YARD, WASHINGTON, D.C.

ROLLING IN WAVES
EFFECT OF VARIATIONS OF FORM ON ROLL

EXPERIMENTAL MODEL BASIN
ERECTED 1898
BUREAU OF
CONSTRUCTION AND REPAIR
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I. GENERAL DISCUSSION.

1. Model Basin Report No. 295 describes an experiment to determine the action of external tanks in damping the roll of a ship. Report No. 301 is a discussion of the probability of synchronism between ships and sea waves. This report is a continuation of the general subject of rolling and describes an experiment to determine the behavior of a ship in waves and the effect of changes in form on roll.

II. DESCRIPTION OF EXPERIMENT.

2. In this experiment a series of seven models was used. The characteristics of the models were as given in the table below.

Model No.	Midship Sect. Coefficient	Block Coef.	L.Ft.	B.Ft.	D.Ft.	lbs.
3107	.86	.60	16.667	2.357	.9825	1447
3108	.92	.60	16.667	2.357	.9825	1447
3109	.98	.60	16.667	2.357	.9825	1447
3110	1.04	.60	16.667	2.357	.9825	1447
3111	1.10	.60	16.667	2.357	.9825	1447
3112	.80	.60	16.667	2.357	.9825	1447
3113	.74	.60	16.667	2.357	.9825	1447

Plate X shows body plans of models.

3. As the block coefficient was held constant the longitudinal coefficient had to vary oppositely to the midship section coefficient. It was realized that two form characteristics were being changed at one time but in an actual ship when the displacement is held constant a change of one form coefficient must entail a compensating change in some other. For this reason the variations of form used in the models are probably very similar to form variations in different types of full scale ships having the same displacement.

4. The models, taken one at a time, were ballasted to the proper displacement and G.M. Each model was ballasted in as nearly the same way as possible to determine the effect of change of form on period. Before running a model in waves a declining angle curve in still water was obtained. The model was then placed heading across the basin near the wave maker and waves of various heights and periods generated. The model was in the trough of the waves. For each period and height of wave train the model was allowed to build up to maximum roll and then a

rolling record was taken using a gyroscope roll recorder mounted in the model. A chronograph attachment provided easy means of determining period. Each model was run with GM's of 1", $1\frac{1}{2}$", and 2". The variation of GM gave a change in model period. Thus by changing the period of the waves, the period of the model, and the height of the waves a wide variety of conditions was obtained for each model.

5. The period of the waves was obtained from the calibration curve of the wave maker and checked by stop watch. The height of the waves was obtained from the calibration curve of the eccentric setting of the wave maker and checked by battens spaced across the basin. Great difficulty was experienced in obtaining trains of waves of uniform period. Mean values had to be taken though care was used to discard runs where variations of period were sufficient to introduce appreciable error. The wave heights were not constant across the basin and mean values were used.

6. In all runs the model was unrestrained, in the trough of the waves, and with no way on her.

III. ANALYSIS OF DATA.

7. The still water period of the model was obtained from the declining angle record with the chronograph record imposed. The still water period of the model at small angles of heel (up to 10°) was taken as the natural period of the ship and designated "Ps." For every run the period of the waves was obtained as described and designated "Pw." The wave length was obtained from the formula:

$$Pw = .44\sqrt{L}$$

The maximum surface slope was closely approximated from the formula:

$$\phi = \pi \times H/L \quad \text{(where H is the wave height)}$$

The record of each run gave θ , the maximum angle of heel for the given wave-period and slope. For every run a value of Pw/Ps and θ/ϕ was obtained. By making a great many runs at different values of Pw/Ps for each value of ϕ a series of curves of θ/ϕ against Pw/Ps was obtained. Each value of ϕ determined one curve of the series. It was found during the experiment that for a given value of Pw/Ps, θ did not vary directly as ϕ; hence a separate curve for each value of ϕ was necessary.

8. The method of plotting the data (θ/ϕ against Pw/Ps) gave curves applicable to all ships of approximately the same size having the same damping of roll characteristics.

9. The declining angle curves were so nearly alike for all models and all values of GM that a mean curve was used for all models. This curve is shown on Plate I. The curves of θ/ϕ against Pw/Ps are shown on Plates II, III, IV, V, VI, VII, and VIII. The curves are very similar for all models. This is to be expected as it was pointed out in Par. 8 that any curve was applicable to ships of nearly the same size and having the same damping characteristics. The models were all the same size and the declining angle curves being nearly identical meant near identical damping.

10. For purposes of comparison theoretical curves were computed for θ/ϕ against Pw/Ps for various values of ϕ. These curves are plotted on Plate IX. The method of computation is described in Appendix I.

11. The periods of the models for a constant GM showed such small and non-uniform variations that no conclusions could be drawn.

IV. DISCUSSION OF DATA.

12. A study of the declining angle curves indicates that:

(a) Variations in form characteristics as accomplished on the models have very little effect on the damping of roll characteristics.

(b) Variations of GM of the order accomplished on the models have very little effect on the damping characteristics.

These facts would suggest that the damping when still in the water is almost entirely due to friction.

13. A study of Plates II, III, IV, V, VI, VII, VIII, and IX indicates:

(a) The amplitude of roll of a ship in waves depends on:

A. The ratio of the periods of the waves and the ship. (Pw/Ps)

B. The wave slope (ϕ).

C. The damping of the ship.

(b) Heavy rolling may be expected only when nearly synchronous (Pw/Ps = .9 to 1.1).

(c) When Pw/Ps is very small the ship will not roll.

(d) When Pw/Ps is very large the ship will closely follow the wave slope.

(e) In sea waves large enough to have appreciable effect on a ship the angle of roll is greater than the wave slope.

(f) If the damping characteristics are known the theoretical curves of a ship rolling in waves closely follow the actual performance.

V. CONCLUSIONS.

14. (a) The bare hull damping of roll of a ship still in the water is almost entirely due to friction.

(b) Changes in GM have little effect on the damping of roll when still in the water.

(c) The angle of inclination of a ship in waves does not vary directly as the wave slope. That is, the roll is not harmonic.

(d) The amplitude of roll of a ship in waves depends on:

A. Ratio of periods of wave to ship Pw/Ps.

B. Wave slope.

C. Damping of ship.

(e) The most important characteristic in determining whether or not a ship is a "roller" is the period.

(f) Within the limits of this experiment changes of form produced no changes in rolling, that is, form had nothing to do with rolling characteristics.

VI. FURTHER EXPERIMENTS

As pointed out in par. 3, the longitudinal coefficients of the models were changed oppositely to the midship section coefficients to hold a constant block coefficient. The resultant change in form of the entire ship was probably not great. As a wave meets the entire ship at one instant it is probable that the overall change of form has more to do with roll than has the change of only one characteristic such as midship section. With this in mind additional experiments in the small basin involving severe changes in general form and greater variations of GM are being prepared.

APPENDIX I.

The theoretical curves were plotted from the formula

$$\theta = \frac{\pi^2}{P_s^2} \frac{\phi \sin\left(\pi/P_w \, t - \alpha\right)}{\sqrt{\left(1 - \frac{P_s^2}{P_w^2}\right)^2 + \frac{4a^2}{\pi^2} \cdot P_w/P_s}} + \beta e^{-\frac{\alpha}{P_w} t} \cdot \sin\left(\sqrt{\frac{\pi^2}{P_s^2} - \frac{a^2}{P_s^2}}\, t + r\right).$$

The second term of this equation is the still water "natural period" oscillation of the ship. Since in waves the oscillations are forced the second term of the equation eventually disappears and only the first term need be considered here. The equation may then be written:

$$\theta = \frac{\phi \sin(\pi/P_w \cdot t - \alpha)\cos\alpha}{1 - \frac{P_s^2}{P_w^2}}$$

(ϕ here is the effective wave slope. In the computations ϕ was corrected to give values of θ/ϕ in terms of maximum surface slope to agree with observed data)

where $\alpha = \text{arc tan} \frac{\frac{2a}{\pi} \cdot \frac{Ps}{Pw}}{1 - \frac{Ps^2}{Pw^2}}$

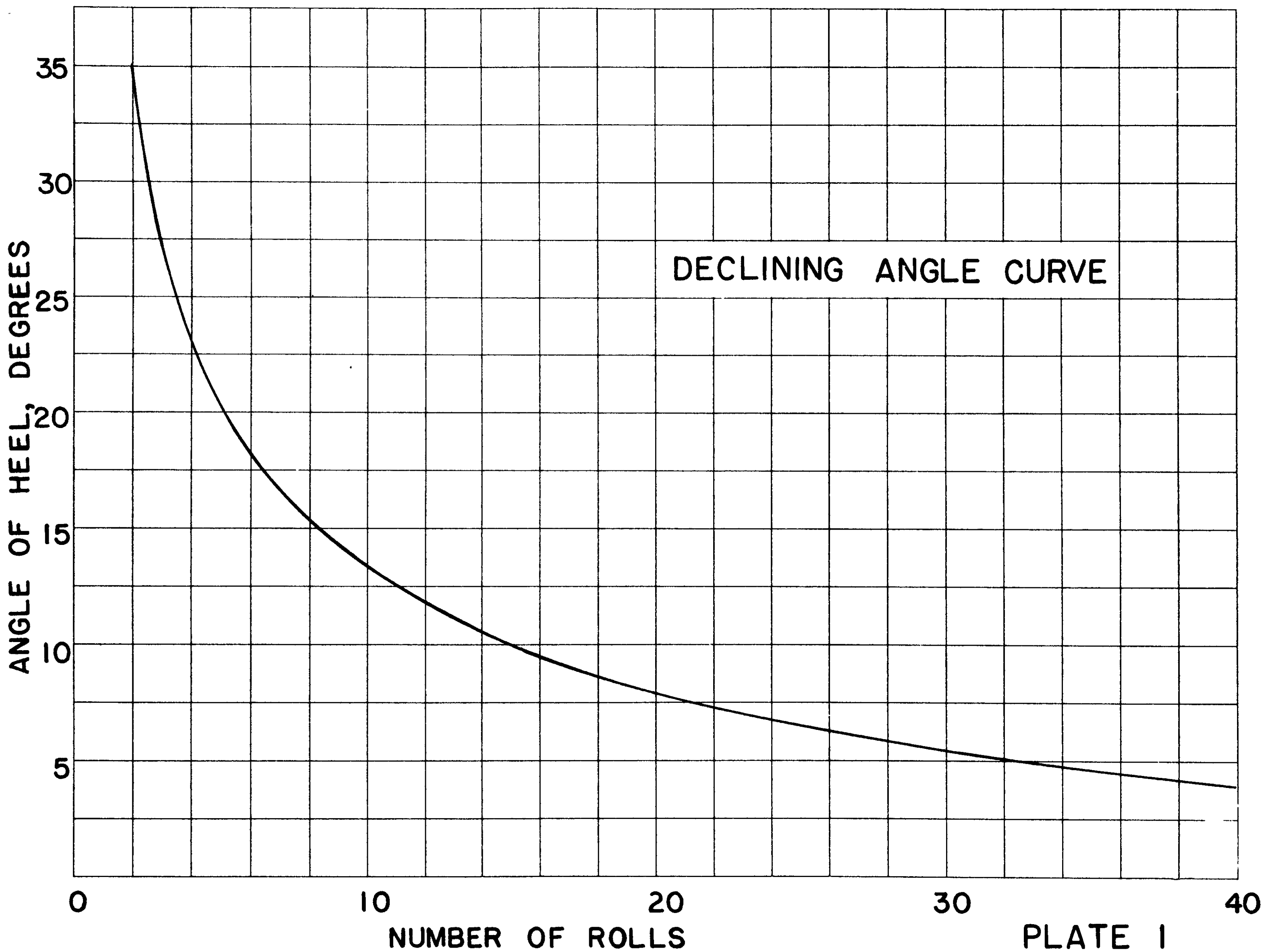
"a" is the damping factor such that

$\delta\theta = a\,\theta$

where $\delta\theta$ = diminution of roll per roll.

As pointed out before the damping curve is not a straight line and the above equation is not true for all values of θ. However the damping curve derived from the declination of roll curve can be taken in short increments such that during the increment the equation $\delta\theta = a\theta$ applies. This step by step process was applied to obtain the spots for the theoretical curves.

It will be noted that the maximum value of θ/ϕ in the theoretical curves falls on Pw/Ps = unity, while in the observed data the maximum θ/ϕ comes at values of Pw/Ps slightly less than unity. This is because at large angles of heel Ps increases slightly and synchronism occurs at values of Pw/Ps less than unity where Ps is the value of ships period at small angles.



DECLINING ANGLE CURVE
ANGLE OF HEEL, DEGREES
35
30
25
20
15
10
5
0
10
20
30
40
NUMBER OF ROLLS

PLATE I

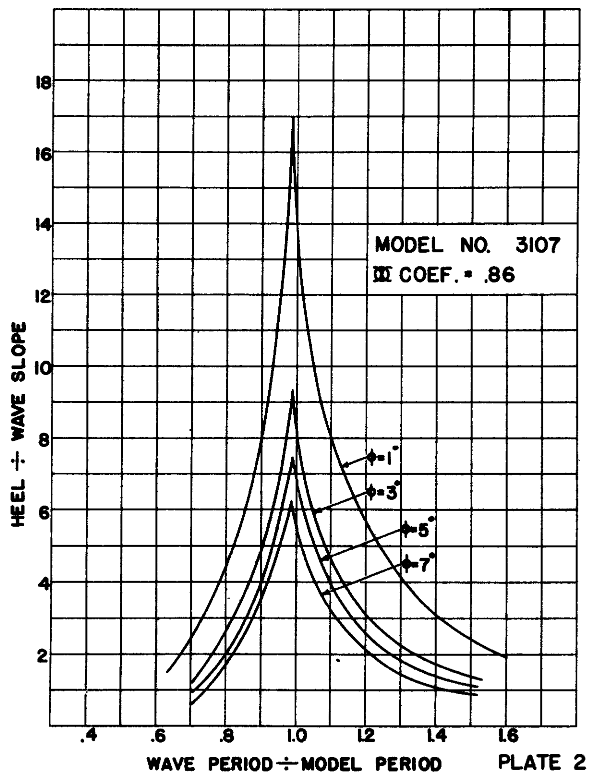
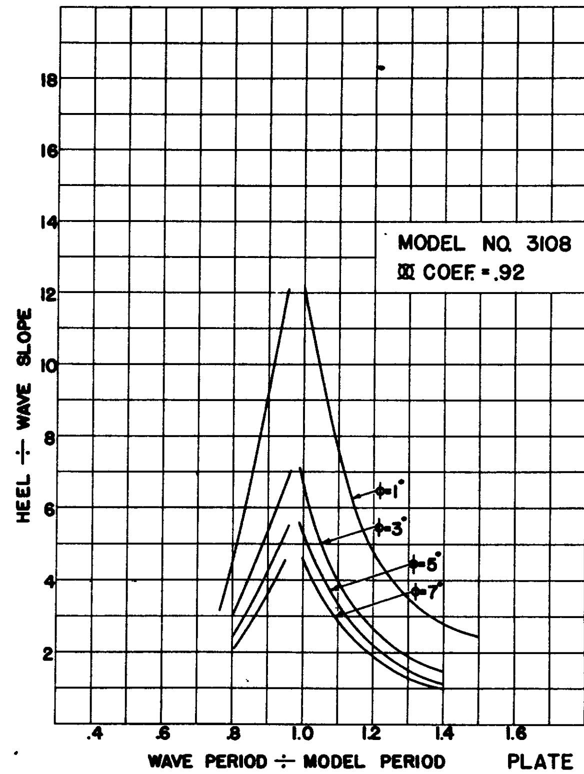


PLATE 2



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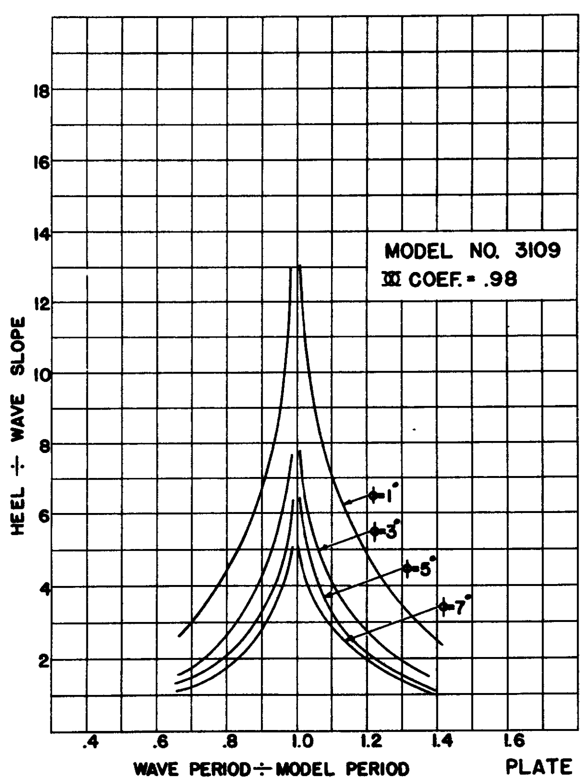

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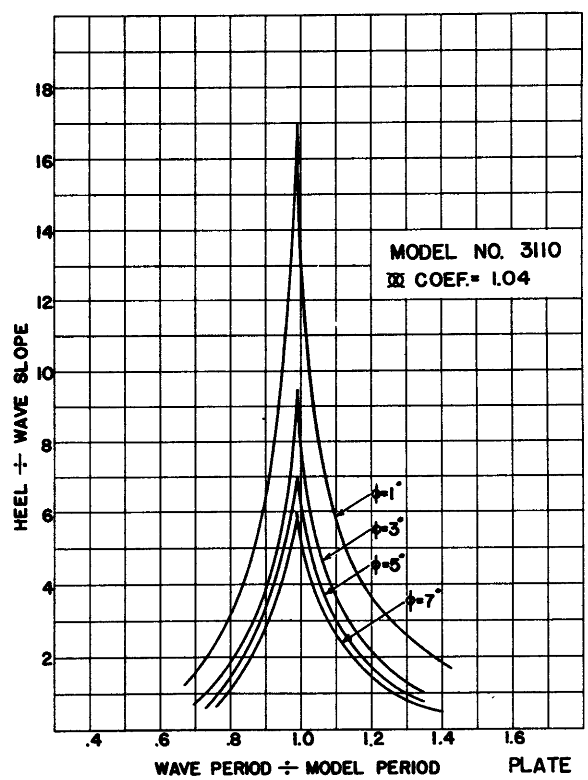

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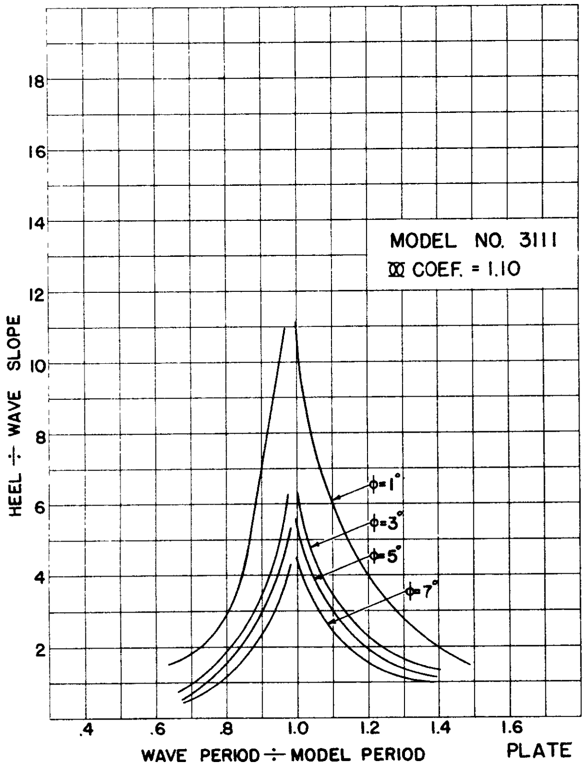

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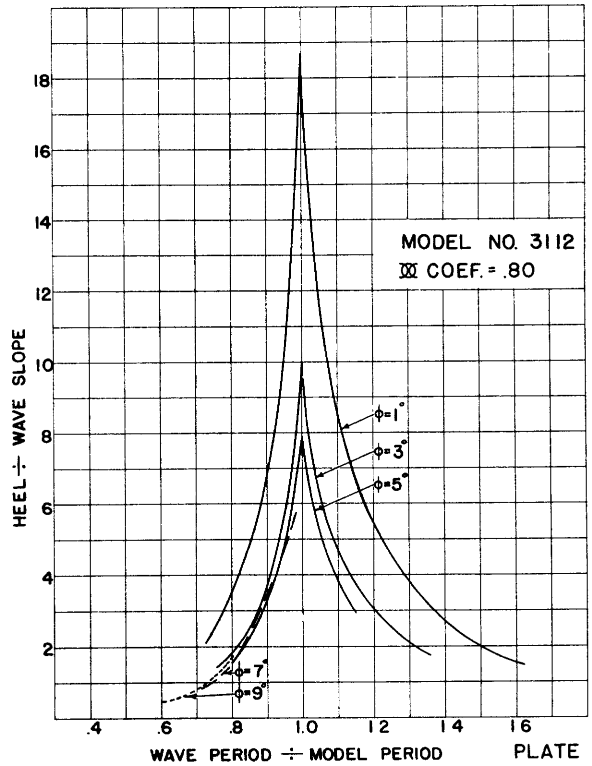


PLATE 7

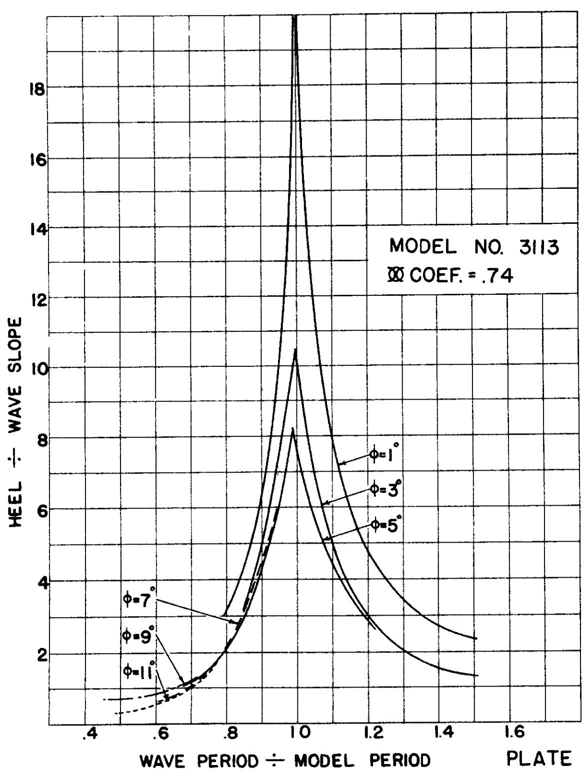


PLATE 8

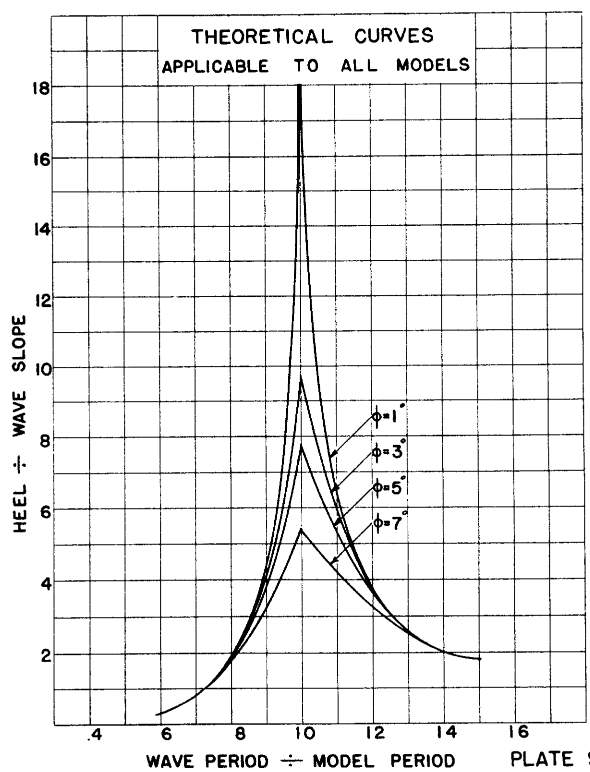
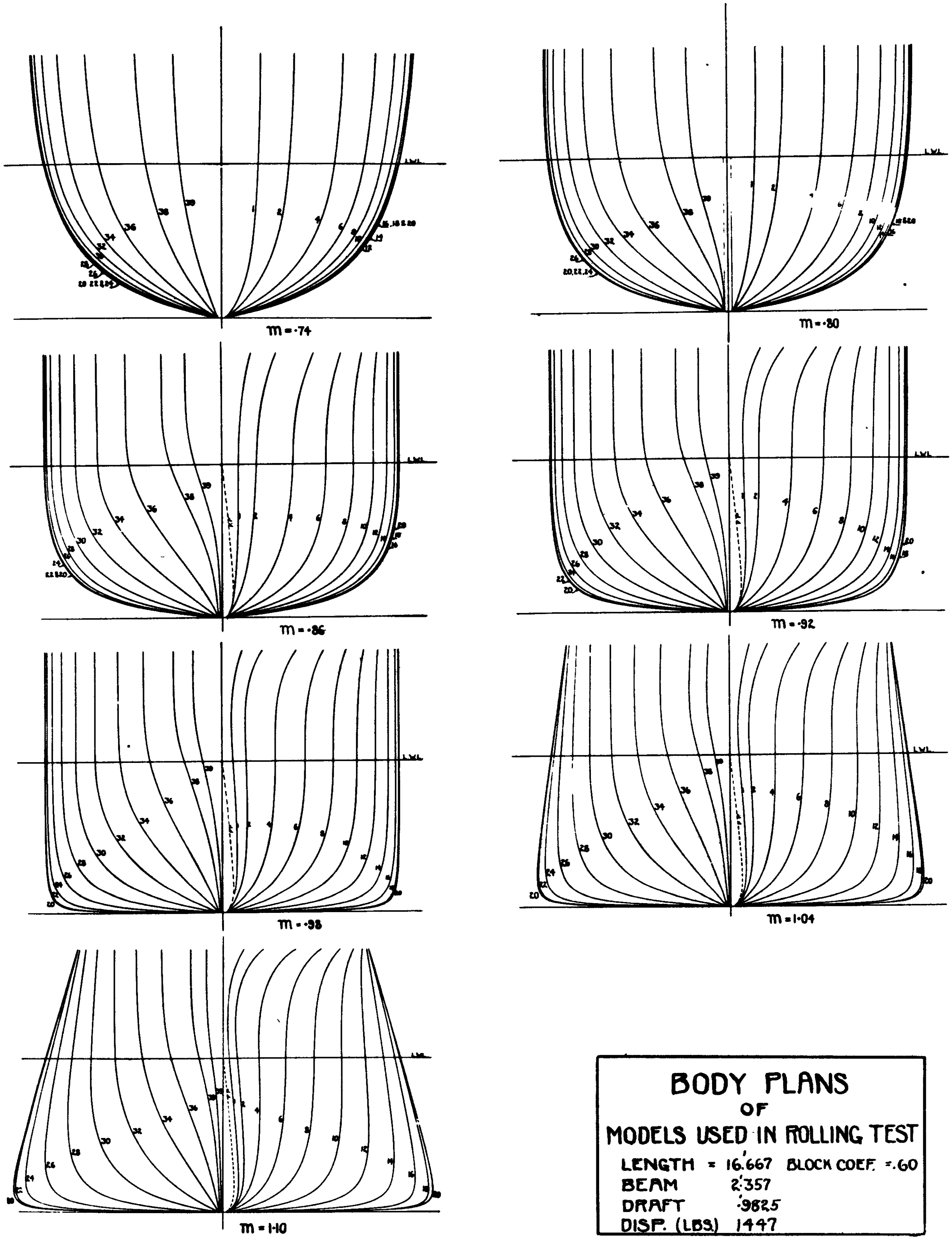


PLATE 9



BODY PLANS
OF
MODELS USED IN ROLLING TEST

LENGTH = 16.667' BLOCK COEF. = .60
BEAM 2.357'
DRAFT .9825'
DISP. (LBS.) 1447