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THE EFFECT OF THE TURN OF THE BILGE ON ROLL DAMPING

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INTRODUCTION

The sharpness of the turn of the bilges, and whether or not they are equipped with keels, greatly determines the roll damping power of the midship section of a given ship. The purpose of this investigation was to determine the effect of the variation of the radius of the turn of the bilge, when without and with bilge keels, on roll damping.

APPARATUS

The tests were conducted in the eighty-foot model basin. A series of five parallel body forms was used. They were all five feet long, of one hundred pounds displacement, and with the metacenter in the water plane. The sides in each case were normal to the flat bottom. Thus in the case where the radius of the turn was zero the bilge was a square corner. For the other members of the series the radius was varied geometrically, being 0.25", 0.50", 1.00", and 2.00" respectively for the models numbered 4, 3, 2, and 1.

These last four models were also tested with bilge keels. The keels were set at an angle of 45 degrees with the normal to the deck and they extended over the full length of the forms. The depth of the keels in each case was such that the bottom edges reached the space line determined by the intersection of the planes tangent to the outer surfaces of the sides and the bottoms. Quantitatively, the depth $d = R(\text{Sec } 45^{\circ} - 1) = 0.41\ R$, where R is the radius of the turn of the bilge. See Figure 1.

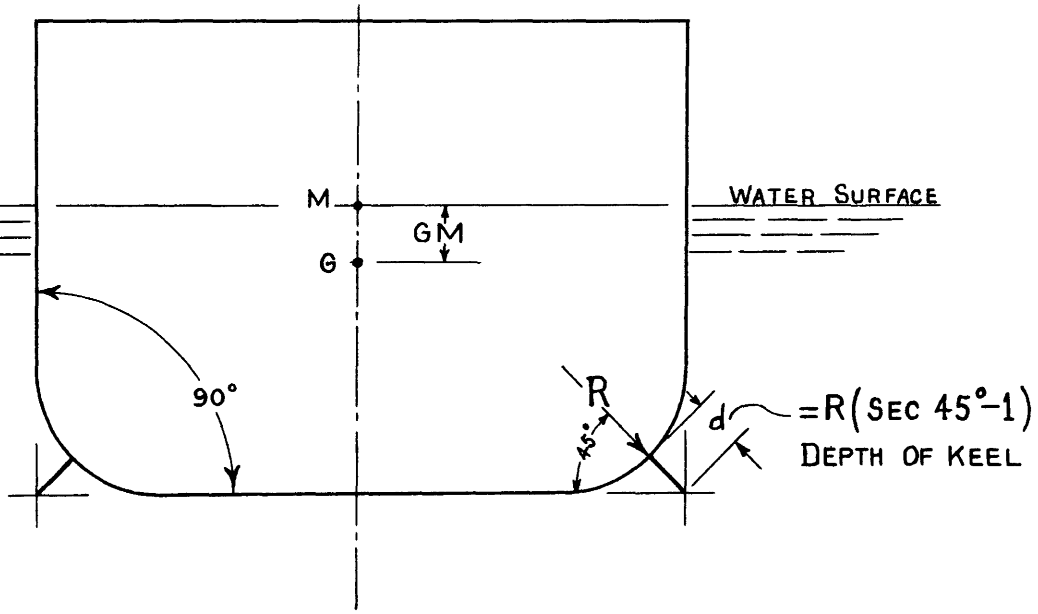

FIGURE 1

Each model was loaded and tested for two different values of GM, 0.50" and 0.92". The rolling period was always adjusted to the one value of 1.56 seconds for a complete cycle when rolling with an amplitude of five degrees or less to a side.

The following table indicates the conditions under which the models were tested.

Table

Model No.	GM	R	d	D	R/D	Condition
1	0.50	2.00			0.442	without bilge keels
1	0.92	2.00			0.442	" " "
1	0.50	2.00	0.82		0.442	with bilge keels
1	0.92	2.00	0.82	4.55	0.442	" " "
2	0.50	1.00			0.226	without bilge keels
2	0.92	1.00			0.226	" " "
2	0.50	1.00	0.41		0.226	with bilge keels
2	0.92	1.00	0.41		0.226	" " "
3	0.50	0.50			0.114	without bilge keels
3	0.92	0.50			0.114	" " "
3	0.50	0.50	0.20		0.114	with bilge keels
3	0.92	0.50	0.20		0.114	" " "
4	0.50	0.25			0.057	without bilge keels
4	0.92	0.25			0.057	" " "
4	0.50	0.25	0.10		0.057	with bilge keels
4	0.92	0.25	0.10		0.057	" " "
5	0.50	0.00			0.00	without bilge keels
5	0.92	0.00			0.00	" " "

where:

R is the radius of the turn of the bilge in inches,
d is the depth of the keel in inches = 0.41 R, and
D is the draft of the model in inches.

The beams of the models remained constant for the series at 10.63 inches within ± .01 in. Figure 2 shows the sections of the models with bilge keels attached to the first four.

METHOD

The models were tested by the method of declining angles. The angles of heel on consecutive rolls in damping were noted and analyzed as described in U.S. Experimental Model Basin Report 433. The initial angle of heel was not obtained however from a static start, as by heeling the form to a side and releasing, but by building up the roll by hand in about two rolling cycles.

Ten declining angle curves were taken for each condition on each model; two curves, one to port and one to starboard, from approximately each of the following initial angles of heel: 3°, 6°, 10°, 16°, 22°.

The different amplitudes were essential since the complete curve could not be obtained in one continuous set of readings before interference by reflected waves from the ends of the basin occurred. These reflected waves, even though small, are especially damaging to the results in that they are normally synchronous waves, being the residue of the waves that were generated by the initial and earlier rolling of the model. Figure 3 is given to show the break occurring in the declining angle curve when data are taken after these reflected waves return to the model's position in the basin.

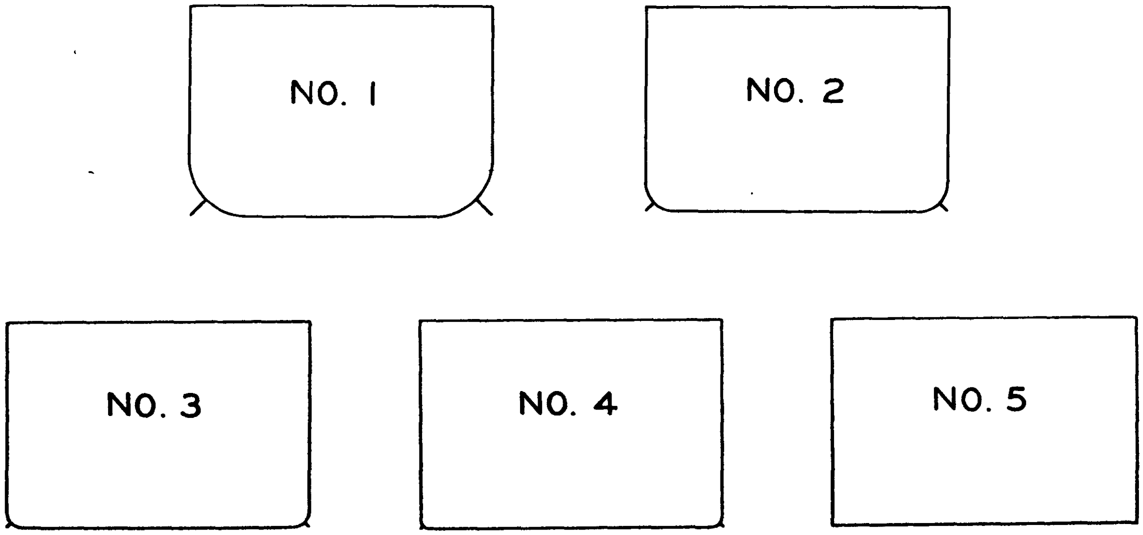

FIG. 2 SECTIONS OF THE FORMS

RESULTS

The results of these tests are given graphically in figures 4, 5, 6, and 7. Figures 4 and 5 give the bare hull results respectively for the two selected values of GM, 0.50 and 0.92 inches. Similarly Figures 6 and 7 give the results for the forms when equipped with bilge keels.

Figures 4 and 5 show that the damping increases rapidly and quite uniformly as the radius of the turn decreases geometrically as specified above. These curves for the bare hull condition also indicate that the damping at the larger amplitudes of rolling is different from that at the smaller amplitudes. The approximate location of this change is indicated by the arrows. It is noted that this change occurs at decreasing amplitudes as the radius of the turn of the bilge decreases and commences with zero amplitude for the condition where R equals zero. This latter is also indicated for all conditions when the forms are equipped with bilge keels. See Figures 6 and 7.

The bends in the damping curves for the bare hull conditions noted above are associated with a change in the stream line flow around the turn of the bilge. The mechanics of the phenomena, simply that of the formation of a wake, as pointed out by Prof. Bryan in 1900, is indicated in Figure 8. Here the P_1 pressures are mainly the static heads of water. They are augmented slightly by the decrease in relative motion experienced by the water as it is caused to move with the form. Due to the relative flow of water around the turns of the form as the latter rotates at small amplitudes the negative P_2 pressures develop. As the amplitude of rolling increases, velocity increases and at some amplitude, depending upon the sharpness of the turn, the flow separates from the form, creating a region of dead water or wake under low pressure during a small part of the rolling cycle. For further increases in the amplitude, P_2 decreases still more, while both the size of the area of hull covered by dead water and the fractional part of the cycle through which it exists increase.

The moments of these pressures about the rolling axis as indicated in Figure 8 are all such as to oppose the natural rolling motion of the form and thus produce damping. The effectiveness of these moments in damping will increase rapidly with the amplitude since the work each does varies as the product of the pressure by the area over which effective by the mean moment arm and by the arc of the cycle through which it exists.

In the absence of actual pressure measurements it appears from analogy that most of the damping is due to the work done by the P_2 pressures. The areas over which the P_1 pressures act on the rounded turns in the absence of bilge keels is abbreviated in the sense that the P_2 pressures are effective over the greater part if not all of the area on the turn.

With bilge keels added the damping in each case is increased beyond that experienced by the full square form. Also, the greater the keels' depth, within the limits of the sizes tested, the greater is this increase. See Figures 6 and 7.

The cause of the increment is attributed to the fact that the presence of the 45 degree keels partially reverses the flow before the water can go around the turn. See Figure 9. This intensifies the conditions which increase P_1 and create P_2, and thus the damping moments increase due to a further increase and decrease respectively of these pressures.

It is also noted, for the 'no bilge keels' condition, that the discontinuity in the flow begins at a smaller amplitude of rolling for the smaller metacentric height, the period being held constant. The reason for this is not fully evident but it would be partially due to raising the axis of rolling relative to the form as the center of gravity is raised. This would cause an increase in the velocity of the bilge through the water for a given amplitude of rolling motion and would thus produce the critical velocity at a lesser amplitude.

Qualitatively the results of this investigation show that damping increases rapidly with the curvature of the turn. They also show that bilge keels when added so as to extend out to the corner as specified in the design of the forms tested give considerable added damping over that of a simple square bilged form.

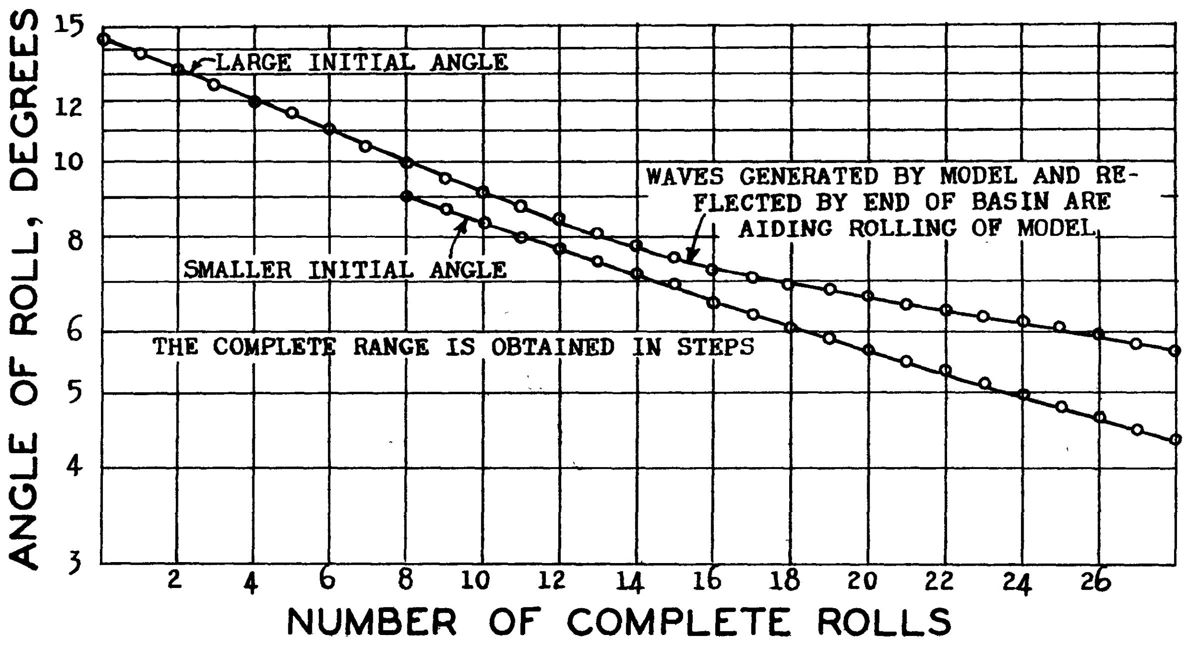

FIGURE 3 DECLINING ANGLE CURVES SHOWING EFFECT OF REFLECTED WAVES

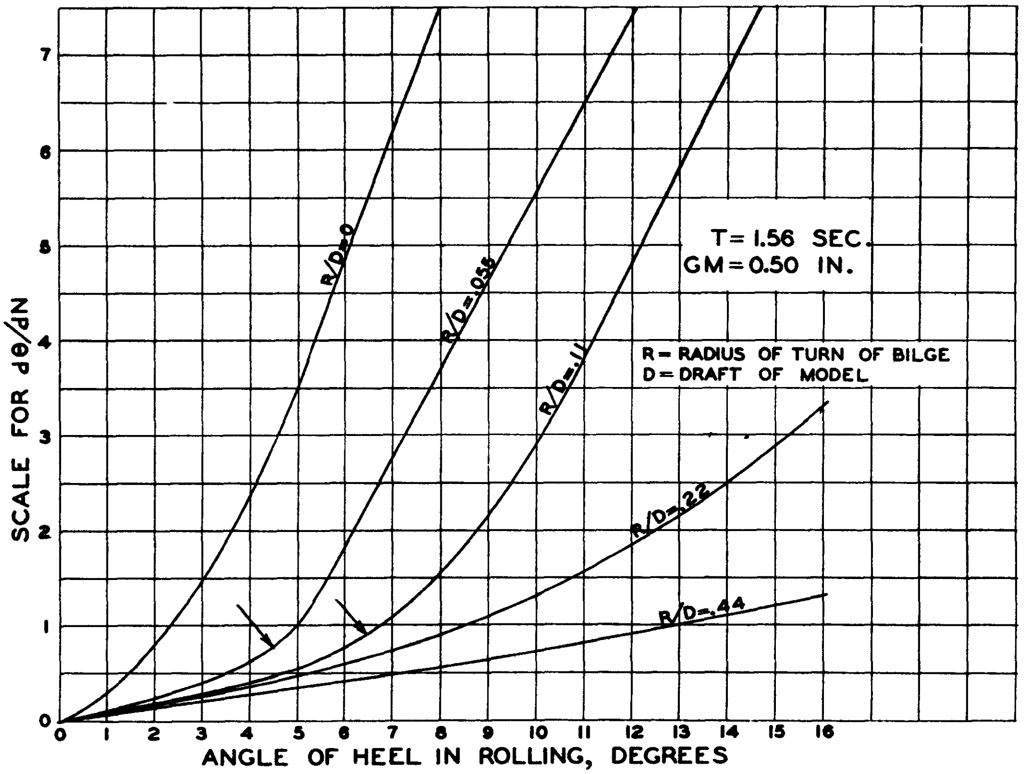

FIGURE 4 ANGULAR DAMPING WITHOUT BILGE KEELS

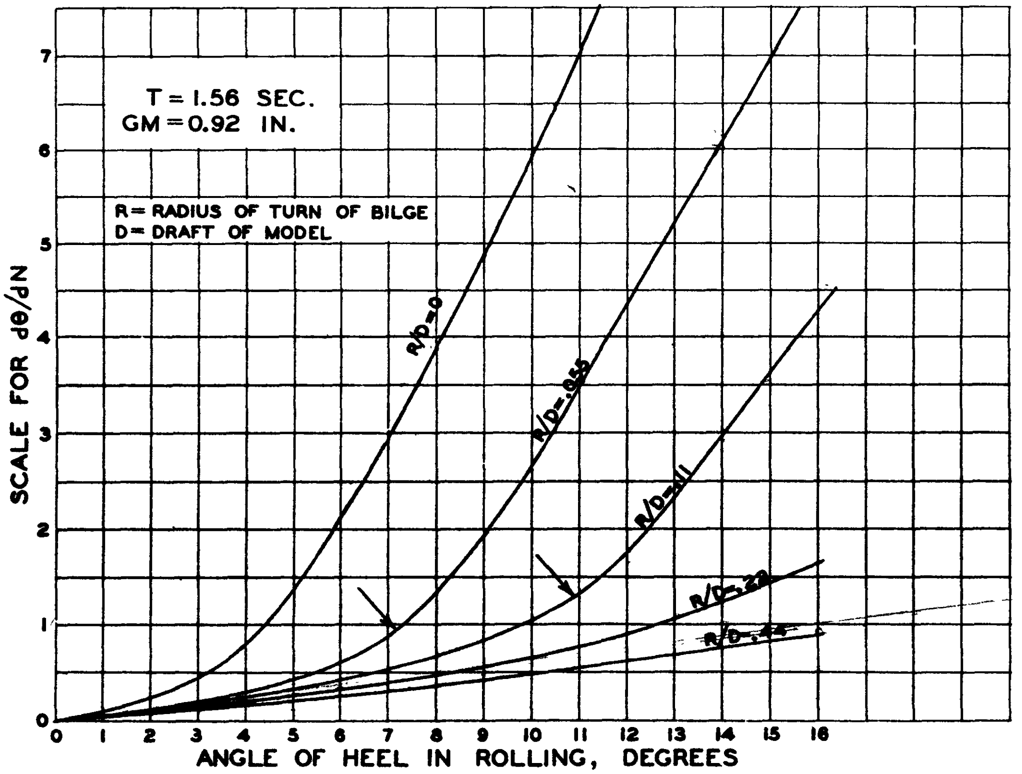

FIGURE 5 ANGULAR DAMPING WITHOUT BILGE KEELS

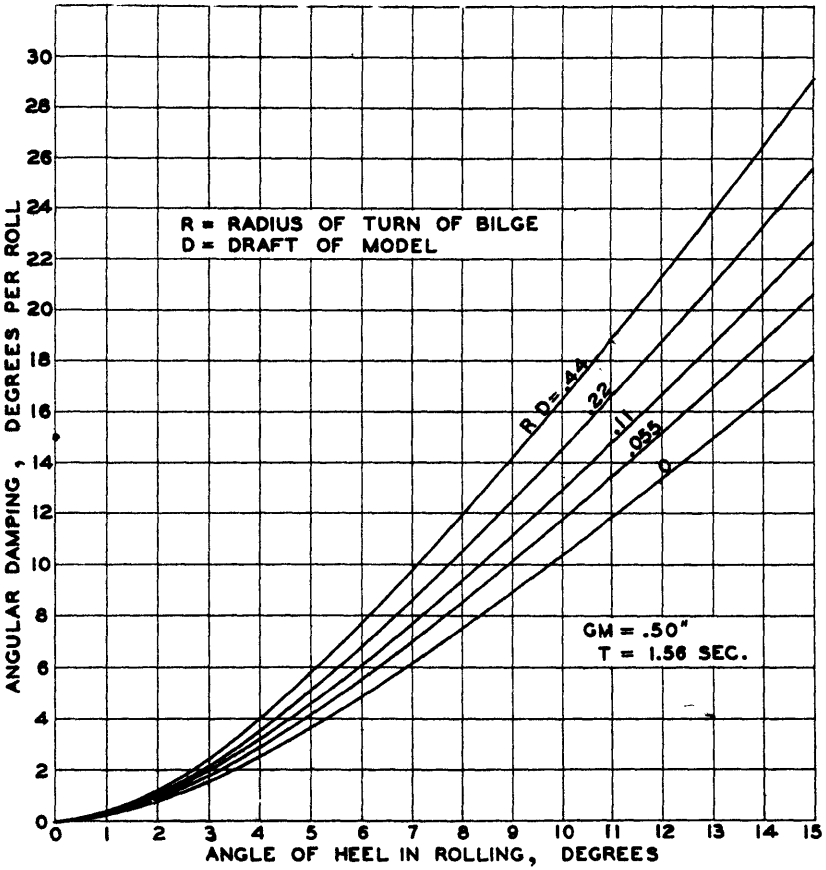

FIG. 6 ANGULAR DAMPING, BILGE KEELS TO CORNER

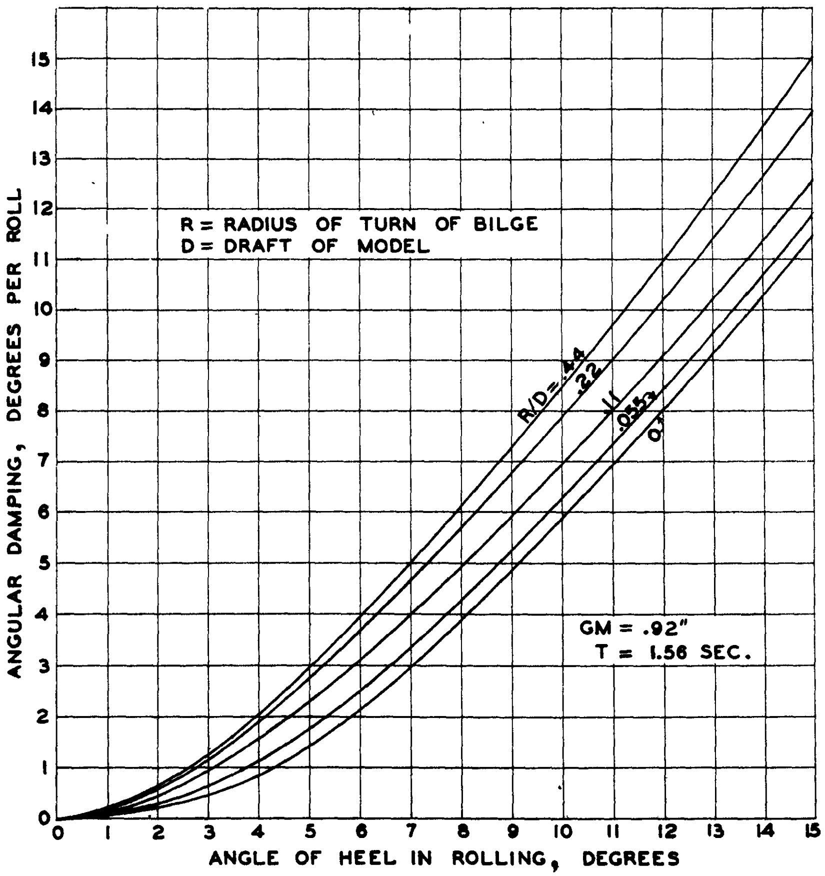

FIG. 7 ANGULAR DAMPING, BILGE KEELS TO CORNER

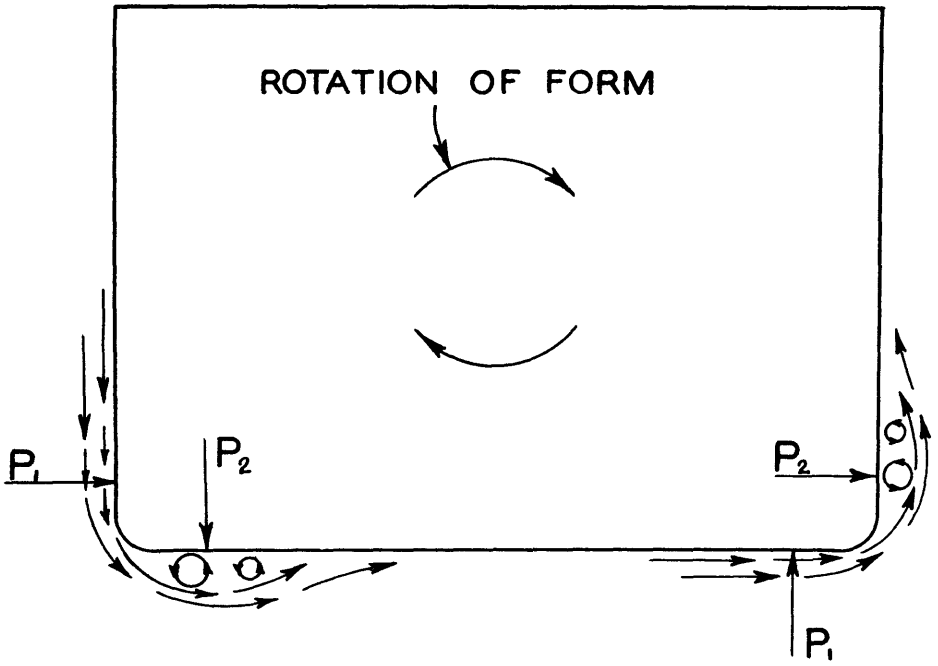

FIGURE 8. FLOW WHEN WITHOUT KEELS.

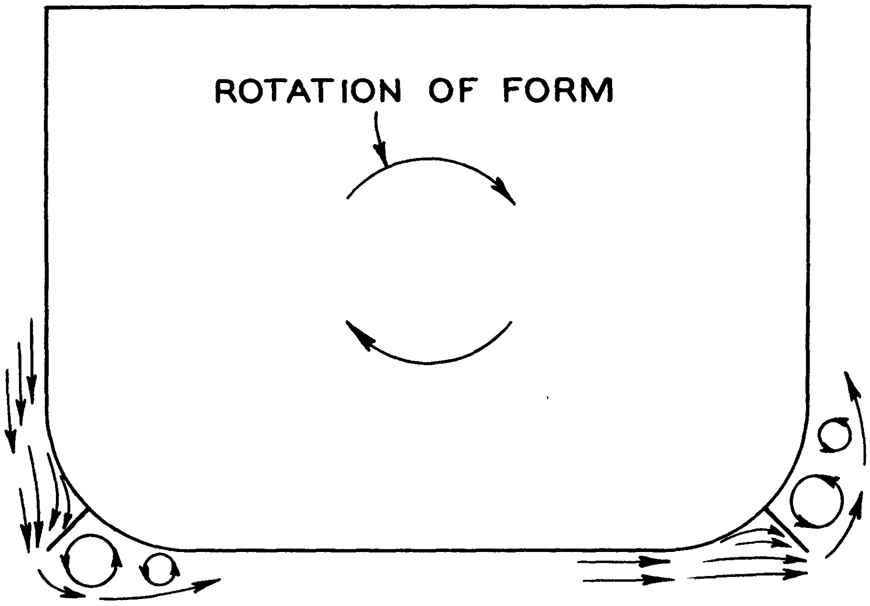

FIGURE 9. FLOW WHEN WITH KEELS.