University of Washington
Department of Civil and Environmental Engineering

LAKE CROCKETT SMALL BOAT BASIN CIRCULATION STUDY

R. E. Nece
E. P. Richey

Water Resources Series
Technical Report No. 33
October 1972

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LAKE CROCKETT SMALL BOAT BASIN

CIRCULATION MODEL STUDY

by

Eugene P. Richey and Ronald E. Nece

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Prepared for
Department of the Army
Seattle District, Corps of Engineers
1519 Alaskan Way South
Seattle, Washington 98134

TABLE OF CONTENTS

ACKNOWLEDGMENT

The study reported herein was authorized by Contract No. DACW67-73-C-0027 as issued from Seattle District, Corps of Engineers, 1519 Alaskan Way South, Seattle, Washington 98134, dated 28 September 1972, with the contractor being Dr. Eugene P. Richey, 11018 - 27th NE, Seattle, Washington 98125. The Statement of Work, Appendix A of the Contract is repeated below:

1. Construct and test a hydraulic model of three basin layouts and furnish a report containing photographs and an analysis of test results.

2. The hydraulic model tests will be conducted in the Harris Laboratory at the University of Washington. Tests will include measurements of current patterns for each of the three basin layouts.

3. The three layouts will be similar with respect to having one main entrance channel. Layout variations follow:

   L-1. No other entrance channel.

   L-2. Additional entrance channel at the opposite end of the basin.

   L-3. Box culvert with 400 square foot cross-sectional area for flushing located at the same location as L-2.

Contractor's note: Four layouts worked out in consultation with Corps personnel were tested, rather than just the three described in the Statement of Work above. Dr. Ronald E. Nece, Professor of Civil Engineering, University of Washington, was the project co-investigator. Larry Lewis and Robert Bergstrom, students in the Department of Civil Engineering, constructed the model and assisted in the testing program.

LIST OF FIGURES

LAKE CROCKETT SMALL BOAT BASIN

CIRCULATION MODEL STUDY

Comparative exchange and mixing characteristics for four alternative entrance and auxiliary channel geometries for the small boat basin proposed for Lake Crockett, Whidbey Island, Washington, were evaluated using a hydraulic model in which the tides and the long-shore current were simulated. The gross exchange coefficients per tidal cycle were determined by the dilution of a fluorescent dye, and the internal circulations by sequential photographs of the mixing of tidal waters into an initially 'black' basin. The exchange coefficients ranged from 0.13 to 0.24, but the configuration with the highest coefficient had less favorable internal mixing characteristics, and an exposure unfavorable with respect to wave energy entering the basin. All of the configurations tested had the boat channel taking off from the existing Keystone Harbor; comparison of exchange coefficients with another, similar study indicate that the harbor reduces the exchange ratio for the different configurations by 25-50%.

Model Dimensions

The model conformed to the drawing identified as "Lake Crockett Small Boat Basin, Whidbey Island, Washington," Seattle District Corps of Engineers, File No. D-1-3-57, with layouts dated 1 September 1972. Some minor changes were made in the entrance curvature shown on the original layout for opening "A", to accentuate an inflow jet formation to improve mixing action; the final model layout is shown on Figure 1.

The model scale ratios were:

Horizontal	1 to 500	Vertical	1 to 50
Velocity	1 to 7.07	Time	1 to 70.7

The Marrowstone Point tidal data were used as a basis for tide characteristics with Mean Water Level at 5.3 feet and a tidal range of 5.6 feet, rounded to 6.0 feet. The elapsed time for a tidal cycle in the model was 10 minutes 32 seconds.

The model was constructed by first molding a wire mesh to templates cut to conform to the topography shown on the reference drawing, and then coating this mesh with a thin layer of a cement mortar, carefully sealed and painted. Figure 2 shows the general model layout, with the tide generating mechanism in the foreground.

A westerly current prevails along the shore and past the entrance to the Keystone Harbor, developing from the general seaward flow on the ebb tide, and as a part of a counterclockwise cell driven by the flood tide separating from the headland west of the harbor entrance. This current was simulated in the model by a manifold water jet discharging parallel to the shore to maintain a slight westerly flow across the harbor mouth to transport away any tracer material leaving the harbor.

Operating Procedures

The four entrance configurations were evaluated on the basis of two criteria, (1) the gross exchange rate, with the basin completely mixed at the end of n cycles, and (2) circulation patterns within the basin. The model techniques used were essentially those reported by Nece and Richey[1] and Lewis[2].

1. Nece, R.E. and Richey, E.P., "Flushing Characteristics of Small-Boat Basins", 13th Coastal Engineering Conference, ASCE, Vancouver, B.C., July 1972.
2. Lewis, L.L., "A Hydraulic Model Study of the Tidal Flushing Characteristics of Two Alternative Small-Boat Basin Designs", MS Thesis, University of Washington 1972 (in preparation)

For the first criterion, the selected entrance configuation was dammed off at high tide, and the basin was seeded with a fluorescent dye, Rhodamine B, in the amount of 40 cc of a solution formed by mixing 4 cc of the full-strength in one gallon of water. The basin was mixed thoroughly, and after the residual currents had died off, background samples were taken, the dams withdrawn, and the tide generator started. At the end of n tidal cycles, the dams were replaced, and an extra barrier positioned as shown in Figure 1 to divide the basin into two parts for a better comparison of the influence of the auxiliary channels on gross mixing characteristics. The sub-basins were then mixed completely and 4 samples were taken from each. All measurements of dye concentration were made on a Turner Fluorometer, Model 110.

The circulation patterns within the basin were traced by dying the water with a washable black ink (25 cc), withdrawing the dams, starting the generator, and recording the patterns photographically; a picture was taken at high tide on each of 5 cycles, and at intervals of one-eighth cycles during the fourth cycle. The photographs, appearing as Figures 4-7, provide a qualitative measure of regions of good and poor mixing, and, as the same amount of dye was used on each test, some relative comparisons between different layouts can be judged. Pictures were taken in both black and white and in color; the color slides show more detail and were referred to in evaluating the circulation patterns, but have not been reproduced as a part of this report.

Exchange Rates

Let C_o be the initial fluorescence reading of the mixed, quiescent basin; after one cycle,

$$C = KC_o$$

where C is the fluorescence level after the one cycle and K is a retention coefficient. After n cycles, the average retention coefficient is

$$K = (C/C_o)^{1/n}$$

and the average exchange coefficient is

$$E = 1 - K$$

Lewis[2], in his study on the model of the Des Moines Marina, found that the exchange coefficient was nearly constant after about two cycles, and that values obtained from tests on the average tidal range were essentially the same as those obtained from numerically averaging results from individual neap and spring tidal ranges. Figure 3 is a summary plot of exchange coefficients for one configuration and set of tidal ranges Lewis obtained from the Des Moines Marina model.

The Lake Crockett model was tested under just the average tidal range of 6.0 feet; results of the test series for the four layouts are summarized in Table 1.

Table 1

Retention and Exchange Coefficients
Lake Crockett Small Boat Basin

Layout	Cycles	East Lobe		West Lobe	
		K	E	K	E
A	3	0.87	0.13	0.87	0.13
AB	3	0.86	0.14	0.82	0.18
	5	0.85	0.15	0.83	0.17
AC	3	0.81	0.19	0.84	0.16
D	3	0.80	0.20	0.76	0.24

Discussion

The exchange coefficients summarized in Table 1 were obtained by mixing artificially the basin lobes for each case studied. This technique allows only the comparison of the gross exchange capabilities of the four schemes, and a comparison between the two basin halves for each case.

Layout D has the highest exchange coefficient, as might be expected, since its opening provides a straight path through the harbor to Admiralty Bay. For the same reason, it provides a clear path for wave energy from the southerly direction to pass through the harbor and into the basin. The mass center of the west lobe is closer to the entrance than that of the east lobe, and this favored position shows up in the higher exchange coefficient.

The "A" series openings were laid out with the basin entrance oriented to cut off the flux of wave energy into the basin. The effect of the single, longer, curved path to the basin is apparent in the resultant exchange coefficient being the lowest of the 4 layouts tested.

The "AB" layout has the basic A entrance with the 50-foot open cut on the west side of the basin as an auxiliary circulation channel. A slight increase in exchange coefficient is noted for the east lobe, but the value for the west lobe is increased by about a third over the simple A opening.

The "AC" layout has the basic A entrance and the 10' x 40' culvert connecting the eastern edge of the basin directly to Admiralty Bay. This configuration has the second-best overall exchange characteristics, with the east lobe being heavily favored. However, the flow (both magnitude and direction) through the culvert can be influenced quite markedly by the orientation of the culvert entrance with respect to the long-shore current and wave direction. The difference in elevation between the Bay and the interior basin is slight throughout the tidal cycle and could be dominated by flow conditions at the entrance which could either enhance or inhibit flow through the culvert.

The dimensions for the proposed Lake Crockett Small Boat Basin are comparable to those of the existing Des Moines Marina, for which model data on exchange coefficients are reproduced as Figure 3. The average tidal range used for the Lake Crockett basin would have given an exchange coefficient of 0.31 at Des Moines; the values for the Lake Crockett case are 25% to 50% less than this. This reduction is attributed directly to the damping action of the Keystone Harbor, as noted in the following section.

Internal Circulations

The photos of circulation patterns for the four layouts are presented as Figures 4a-m, 5a-m, 6a-m, and 7a-m for layouts A, AB, AC and D, respectively. The lower case subscript to denote the number of tidal cycles, beginning with zero at the initial high tide; for example, subscript g refers to 3 3/8 cycles in all layouts. There are some general features of the circulations which can be pointed out before referring to specific cases.

Firstly, there is an important difference between the currents and circulation cells developing on the flooding and ebbing tides. On the incoming tide, the flow through the entrance is basically a jet discharging into a large reservoir, tending to separate from the entry walls, and which slowly imparts its momentum toward the creation of rotational cells within the basin as the tide proceeds toward peak flood. The angular momentum of these cells carries well over into the following ebb, and this carry-over effect tends to invalidate the otherwise tempting, irrotational flow analysis for the outgoing tidal flow.

Secondly, the orientation with respect to the main basin of the entrance and any auxiliary channels influences the location, size and intensity of the circulation cells that may develop. In the Lake Crockett basin, each of the two locations for the main entrance tended to create two main rotary cells, but these were not quite alike. The auxiliary channels were located to direct the flood flow tangentially to the major cells to impart the most possible angular momentum to the cells.

The A layout has the curved channel entrance, with no auxiliary channels. The entrance was oriented toward the tip of the convex northern boundary of the basin so that the incoming jet would tend to divide and establish rotary cells in each side of the basin. These did develop, as shown in the Figures 4d, 4l, and 4m. Figure 4g shows that it takes about three-eighths of a tidal cycle for the water in the basin at high tide to reach the outer edge of Keystone Harbor, and another three-eighths of cycle (to Figure 4j) for the new water to pass through the Harbor and enter the basin. Figure 4g and 4h also show the important carryover effect of the gyres set up on the flooding tide, for two cells are still present halfway through the ebb part of the cycle.

When the B opening is added to make the AB layout, the current patterns within the basin appear to be a little more complicated than in the A layout. Figure 5g shows quite clearly the presence of a gyre in the east basin having a different form than that which developed in the A layout. A small, third cell developed in the west basin. The inflow from the B channel seems to shift the main jet slightly eastward to improve circulation there, as well as to improve the conditions in the west lobe. The Figure 5f shows the incoming jet penetrating to the north boundary; its separation from the east boundary at the entrance is quite evident. The water beginning to leave on Figure 5e is that from the west side of the basin; the eastern side is quite effectively blocked at this tidal stage. Water from the eastern half moved over to the western side, and then was carried out on the next ebb.

One might expect Layout AC to behave as the opposite hand of AB, but there were some distinct differences. The main jet never appeared as distinctly as it did in the AB arrangement; apparently the jet from the culvert circles around the eastern shore (Figure 6b) and opposes the main jet. None of the large-scale gyres were established as well as in the AB case. A comparison of the two schemes after 5 cycles (Figures 5m and 6m) shows the AC basin water to be lighter in color, especially in the eastern half.

Layout D has the simplest pattern of the four. The main activity seems to be confined to a pumping in and out along the axis of the main jet; circulation cells were not as distinct as in the other schemes. After 5 cycles (Figure 7m) the east and west extremes of the basin were still quite dark, and the overall comparison with Figure 6m of Layout AC would favor the latter. Although Layout D had the highest exchange rate of the four plans, as measured by the fluorescent dye technique, it had less favorable internal mixing characteristics.

Conclusions

The two methods of determining the mixing characteristics of the basin gave comparable results, except for Layout D, which had the highest exchange coefficient, but left unmixed pockets within the basin. There were distinct improvements in overall mixing achieved by adding either of the auxiliary channels. The AB layout provided a more nearly equal distribution of mixing throughout, since AC tended to benefit the east side particularly. The direction and magnitude of the flow through the C opening are quite sensitive to the long-shore current and wave action at the culvert entrance.

The harbor exerts a damping action on the exchange coefficients for the basin, which amounts to between 25% and 50%. This action masks differences in internal mixing among the layouts that likely would develop if the basin entrances were connected directly to the open waters of Admiralty Bay. This is a design factor to be considered in developing any plans alternative to four studied. Of the four, Layout AB offers the best balance of protection from incident wave energy and mixing characteristics, although the differences among the four with respect to mixing effectiveness was not great.

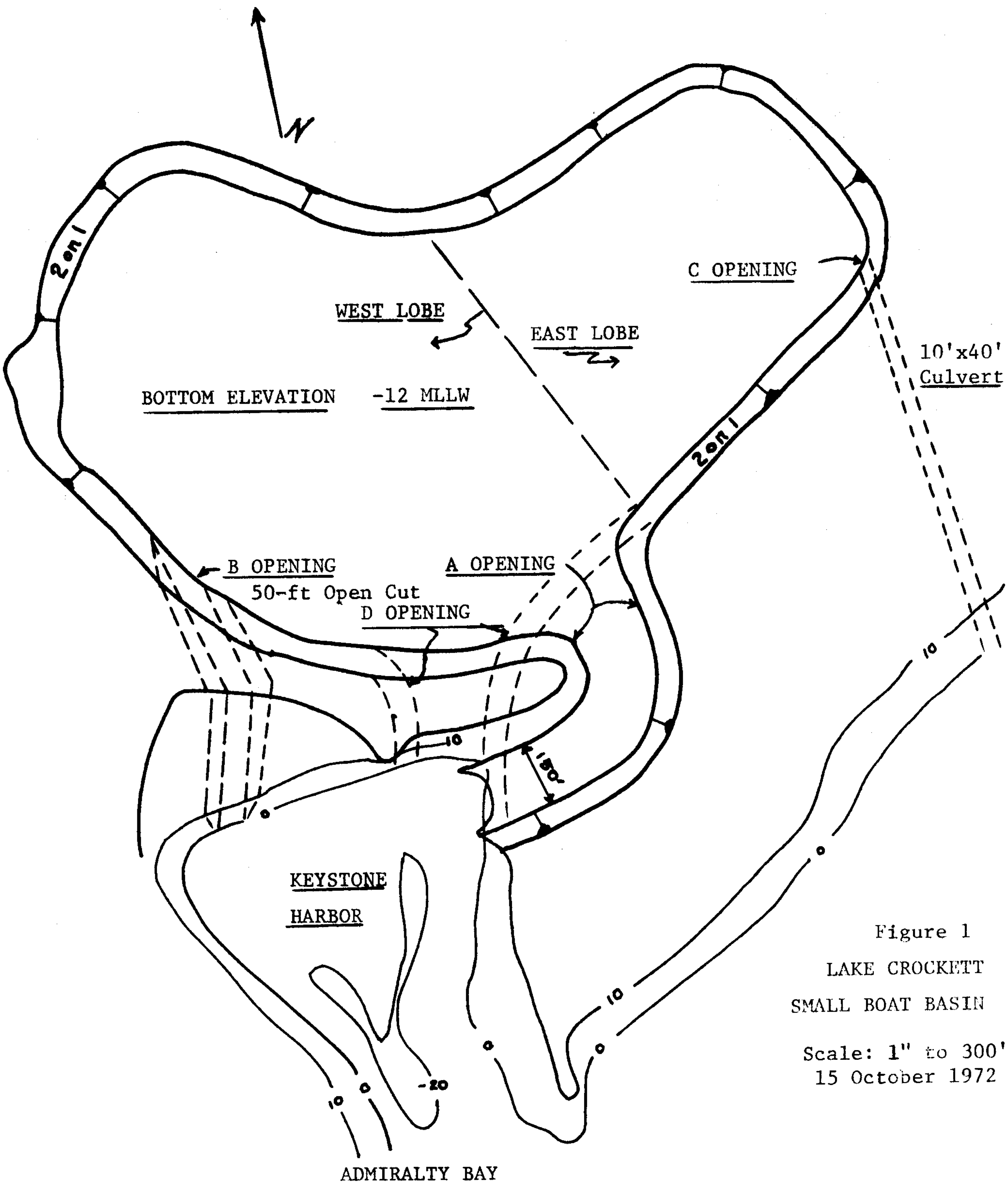


Figure 1
LAKE CROCKETT
SMALL BOAT BASIN

Scale: 1" to 300' approx.
15 October 1972

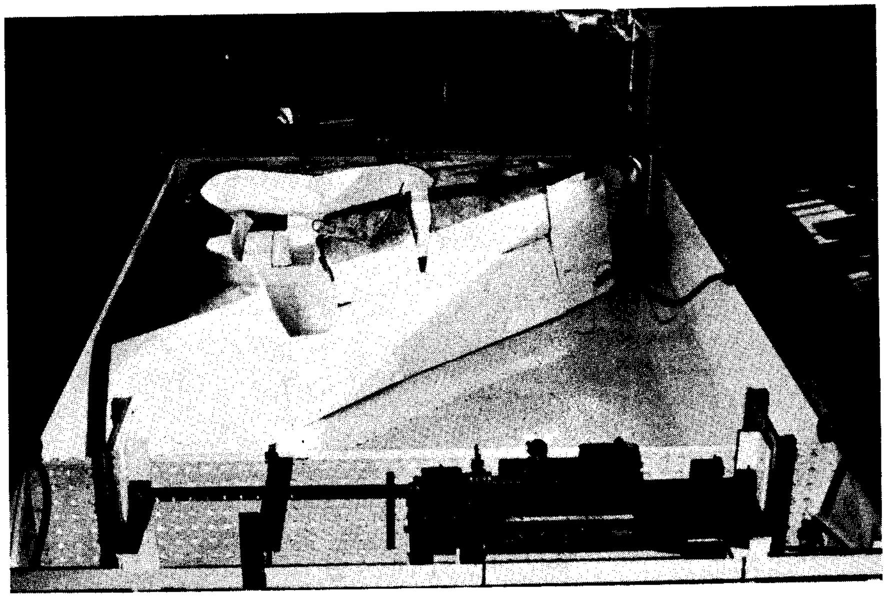


Figure 2. Lake Crockett Model Basin

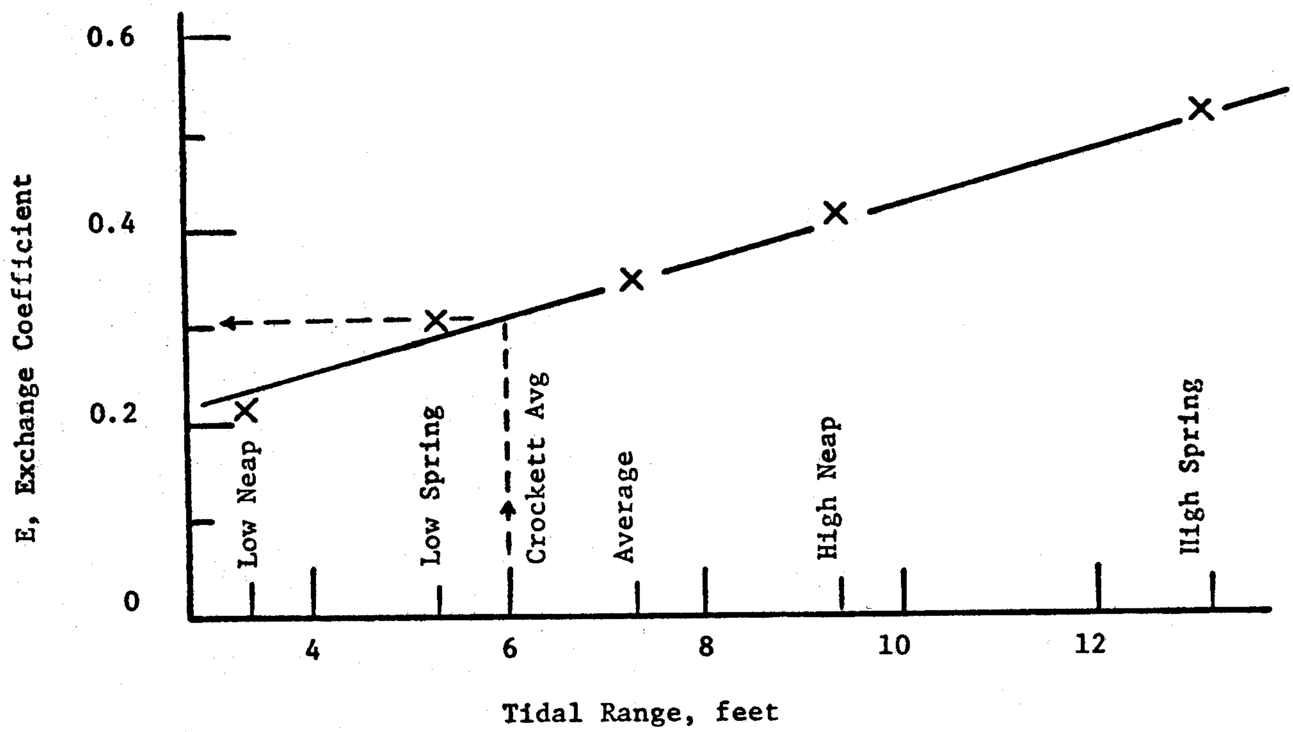
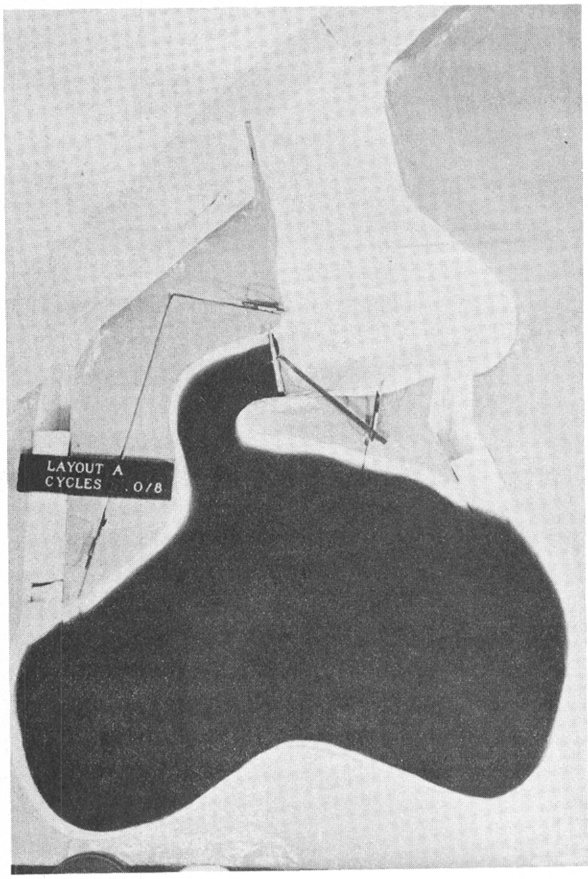


Figure 3. Exchange Coefficient vs Tidal Range, Des Moines Marina



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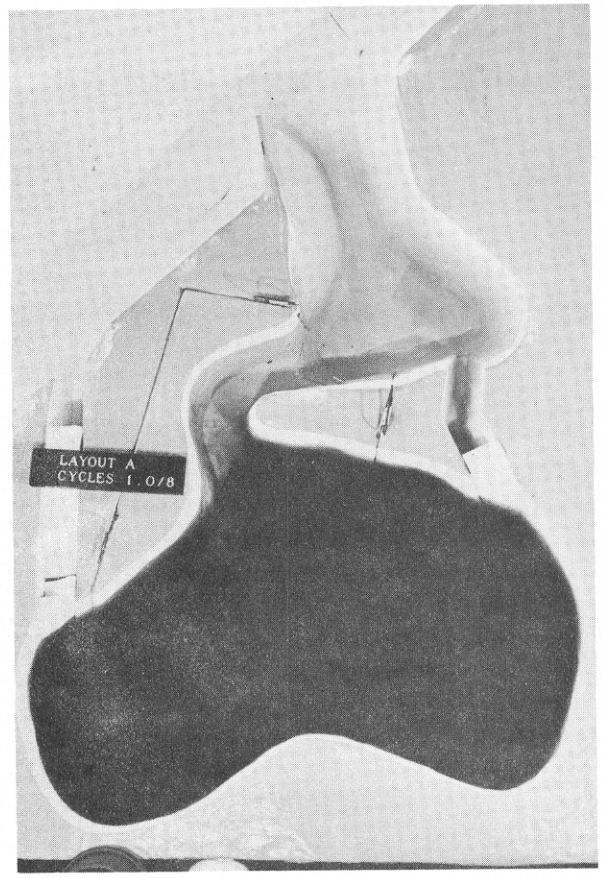


Figure 4b

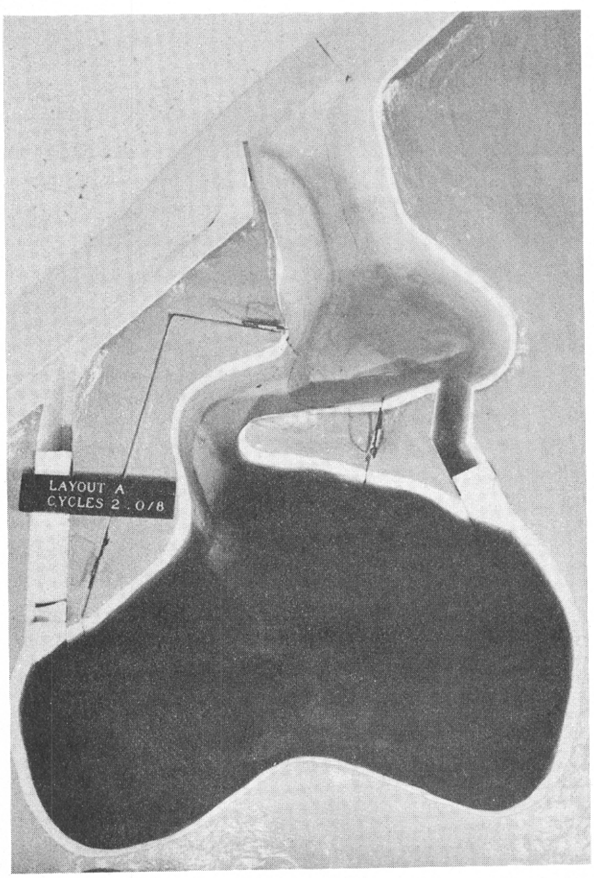
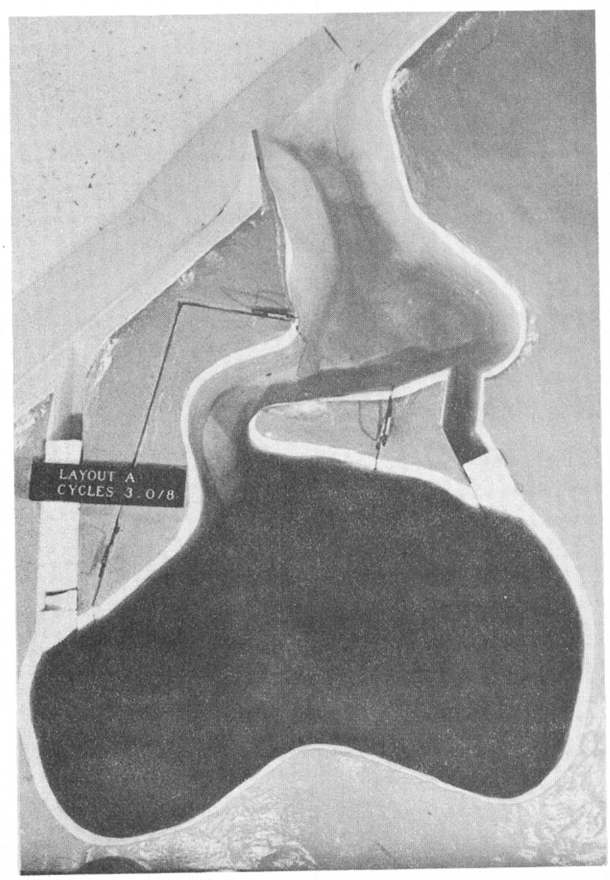


Figure 4c



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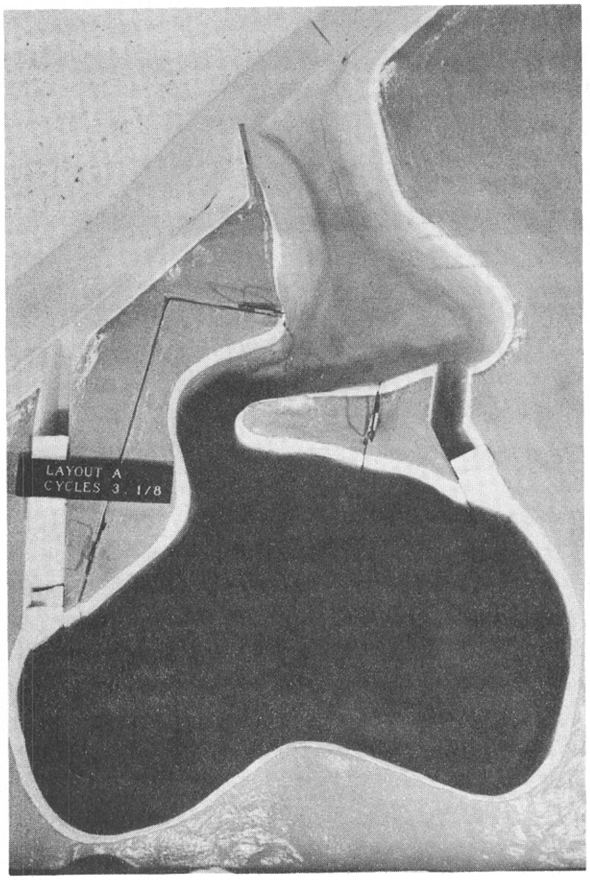

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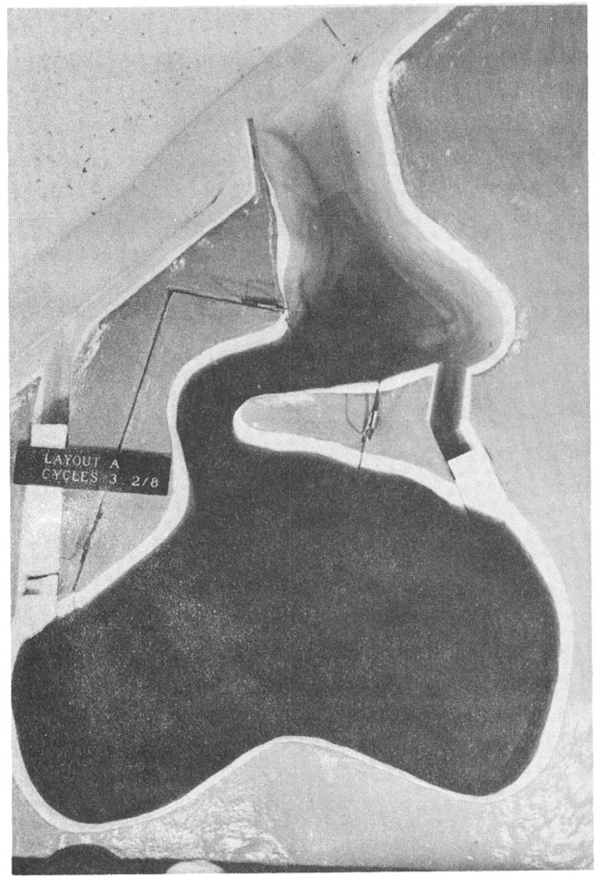

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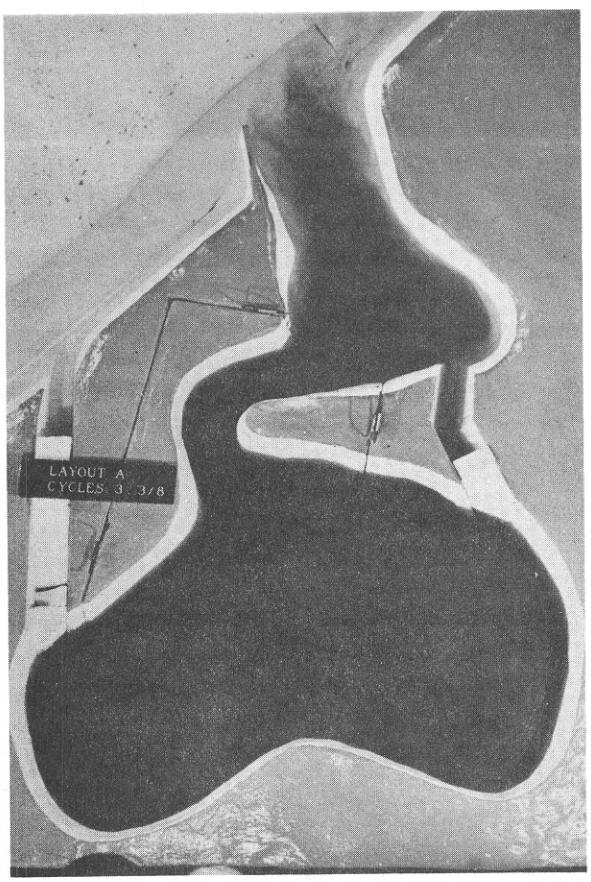

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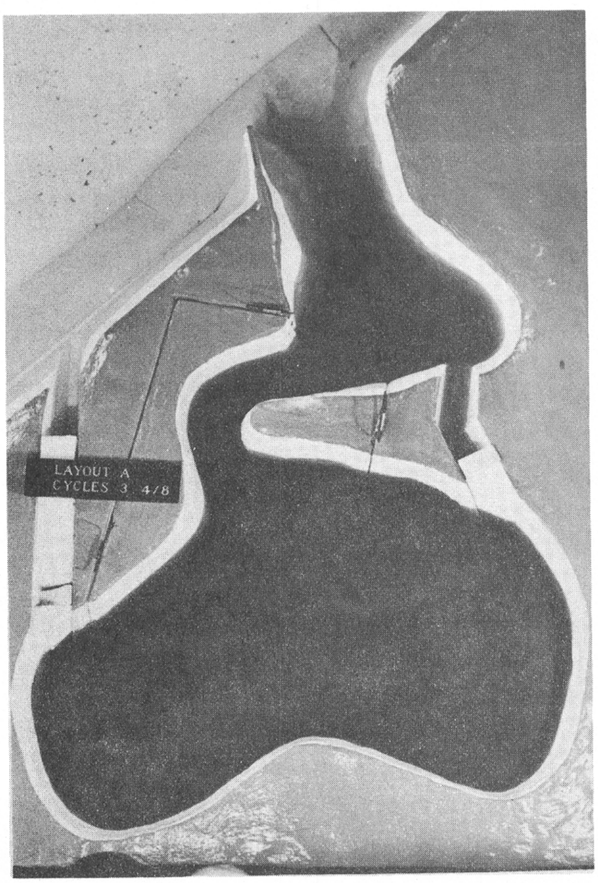

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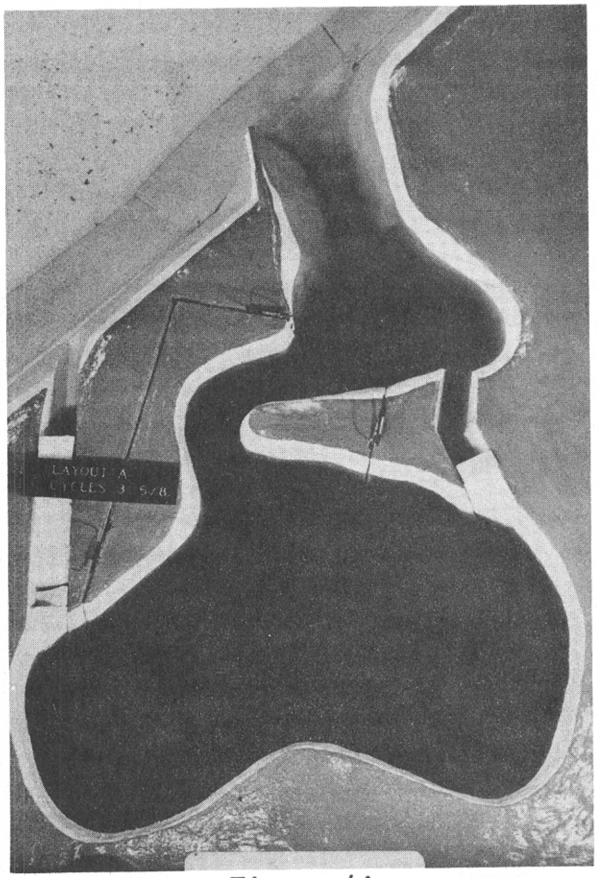
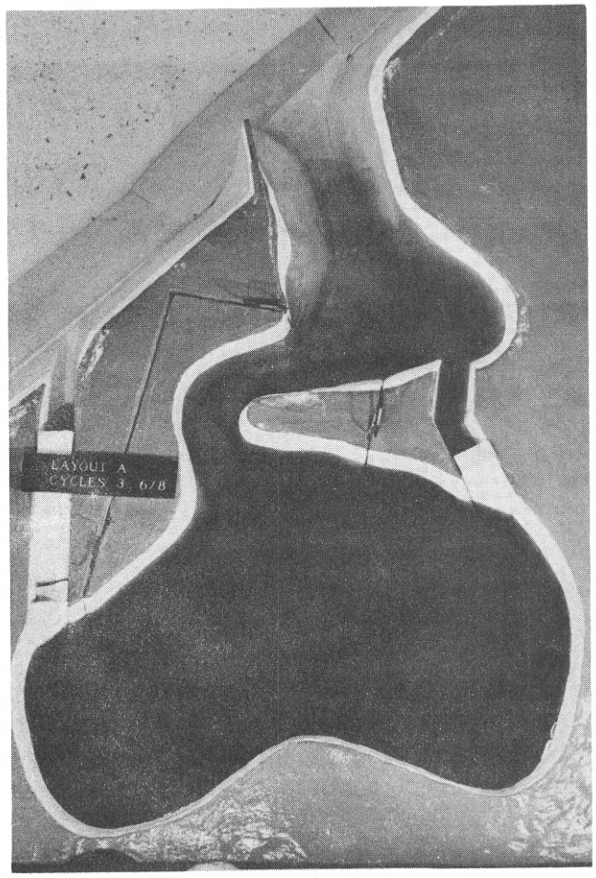


Figure 4i



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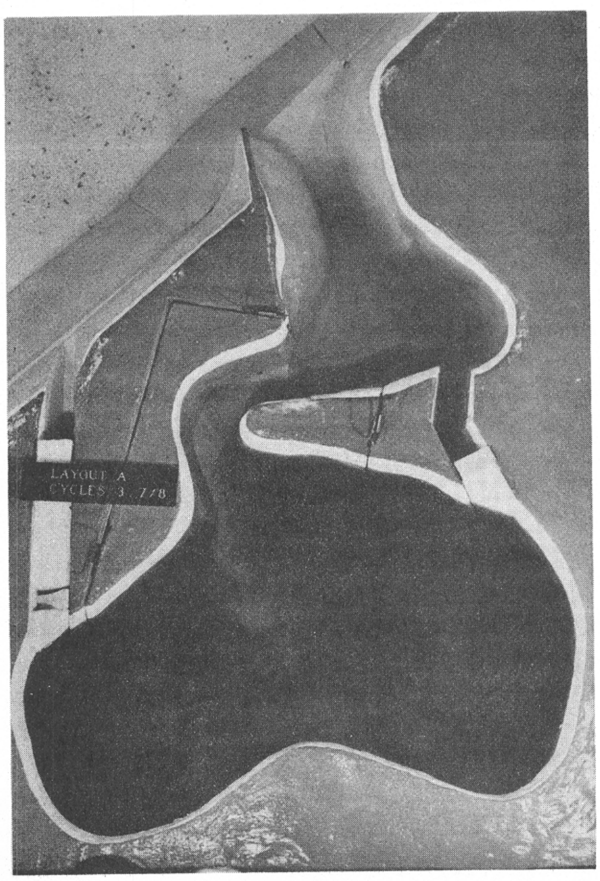

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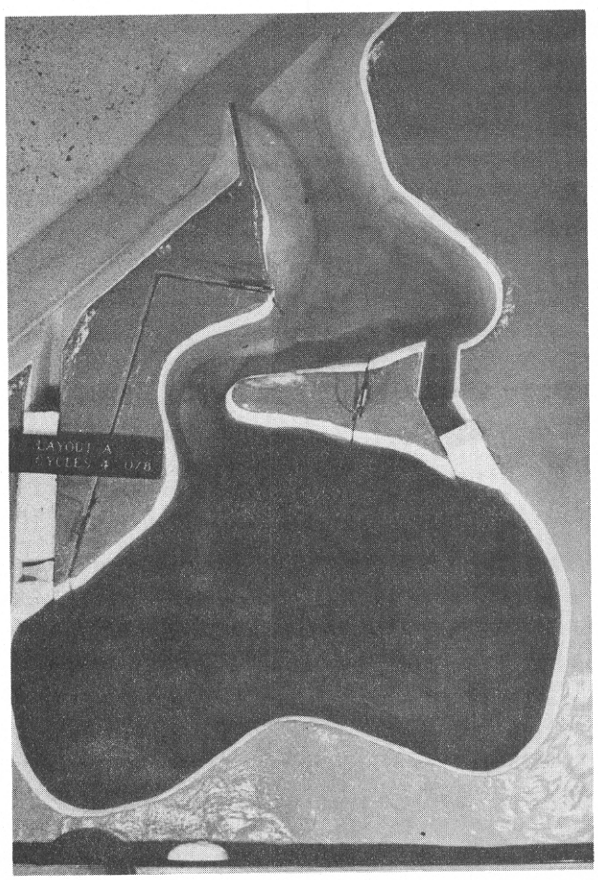

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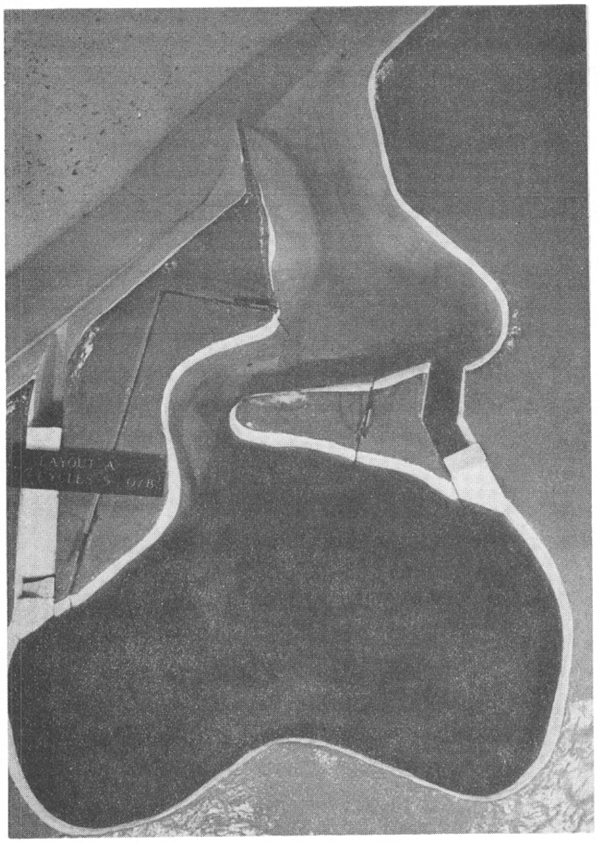

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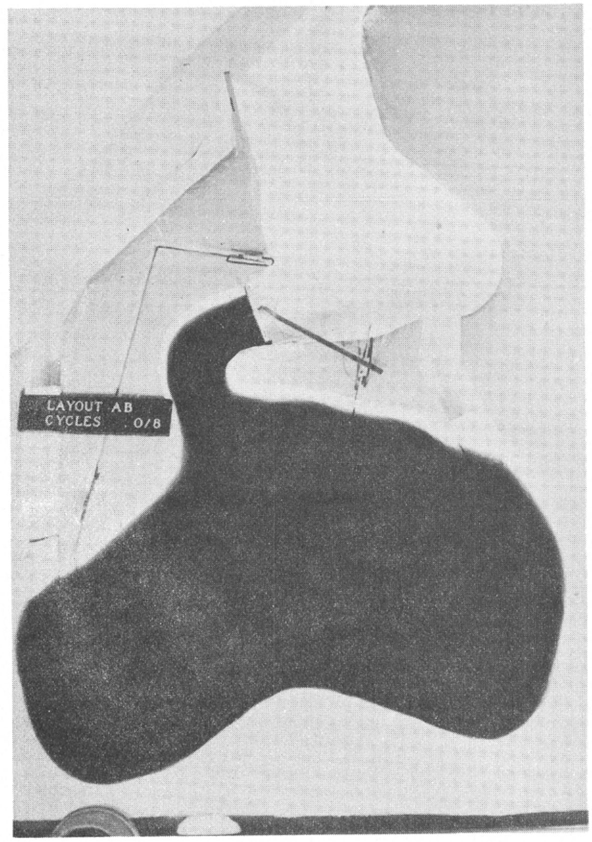

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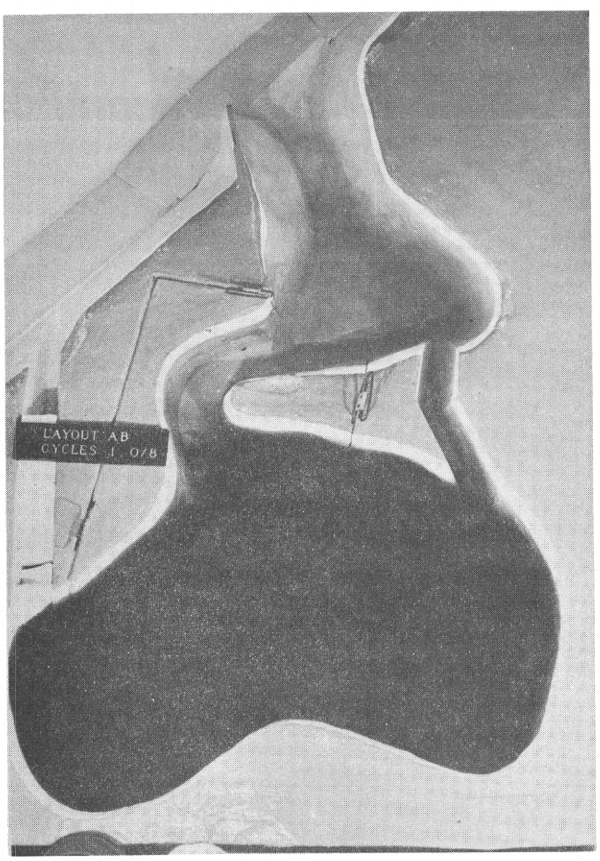

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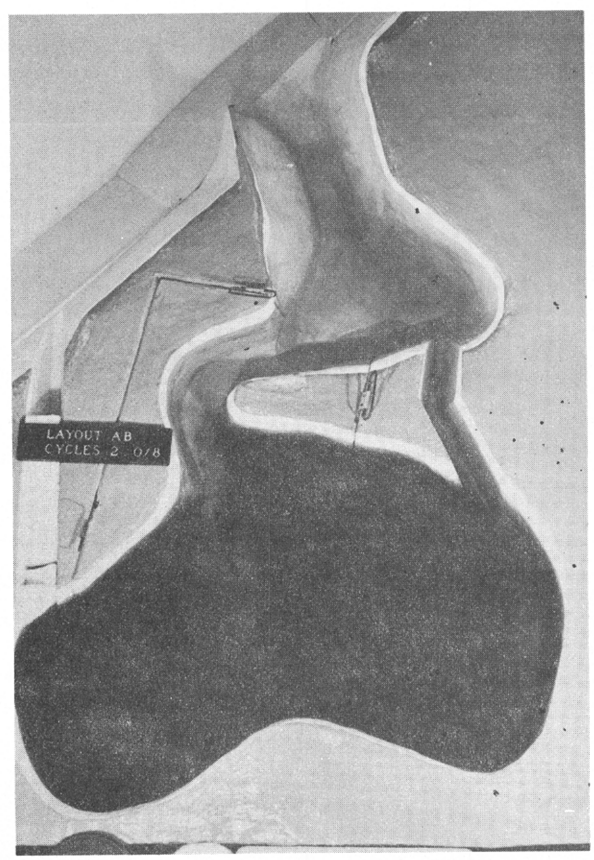

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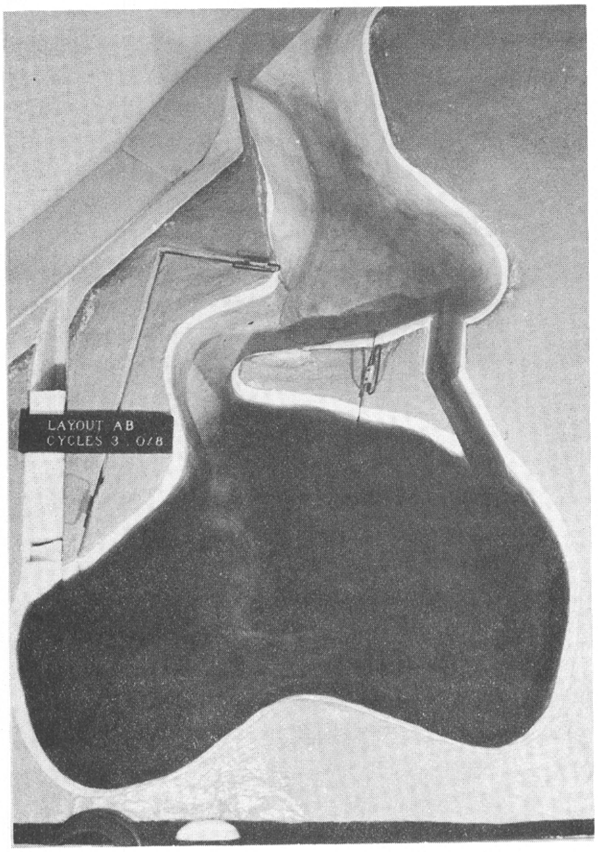

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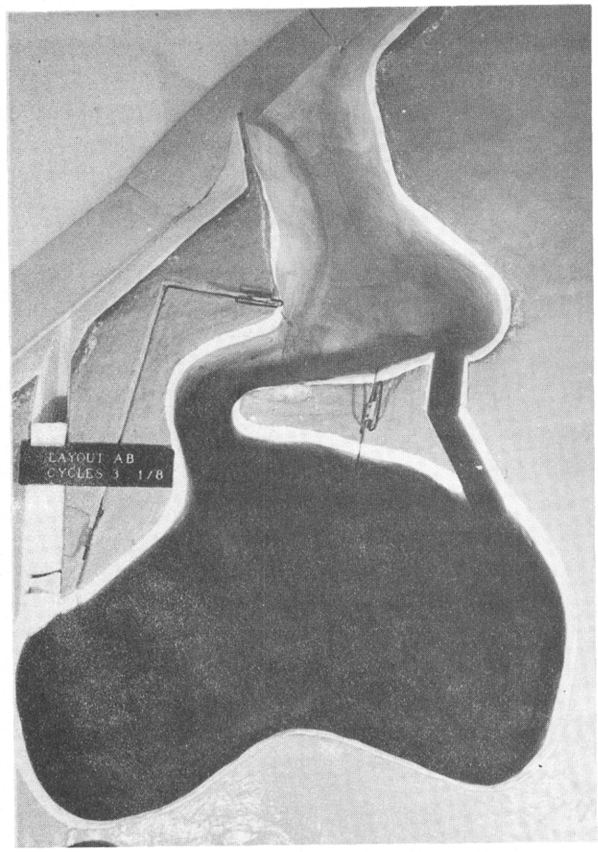

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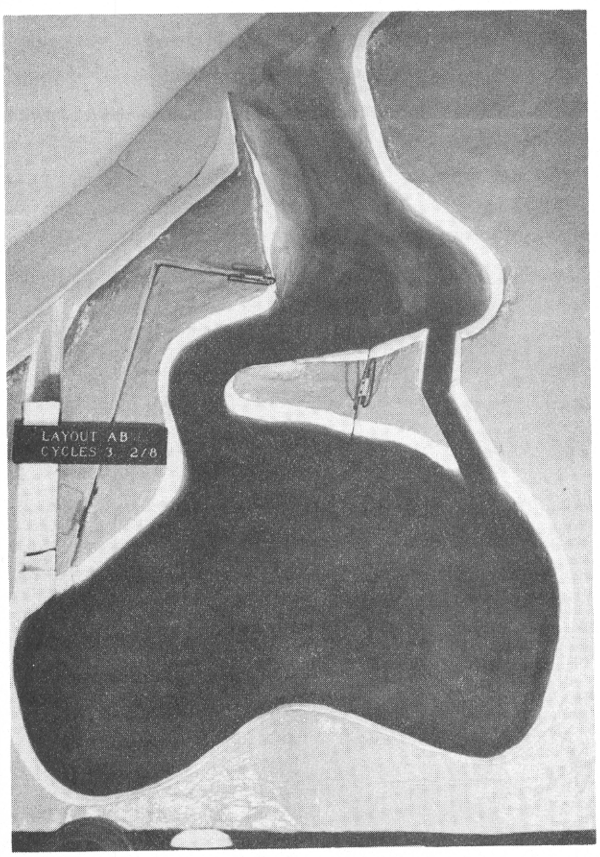

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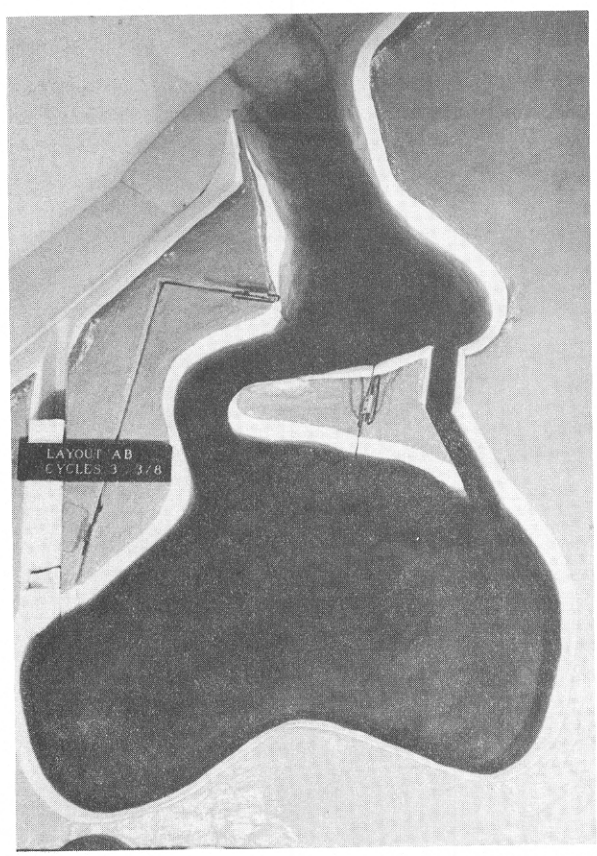

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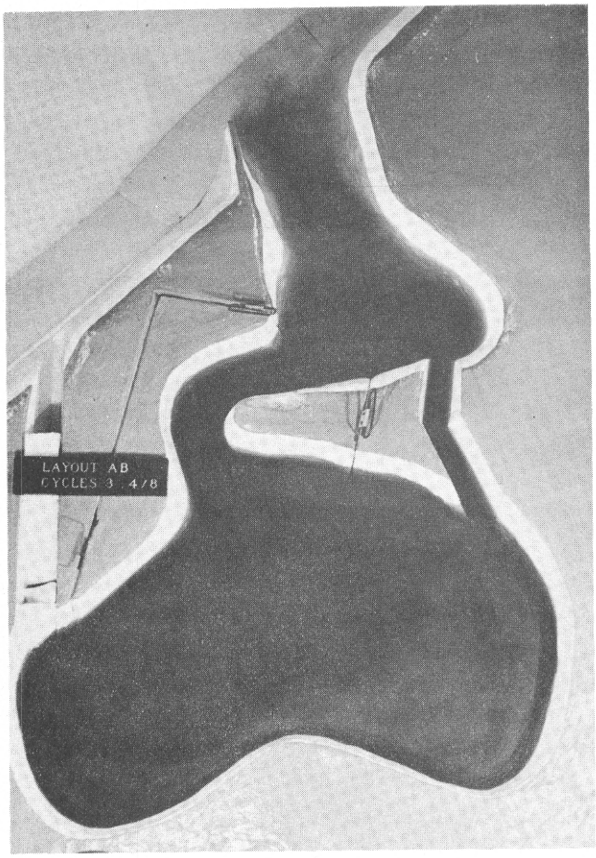

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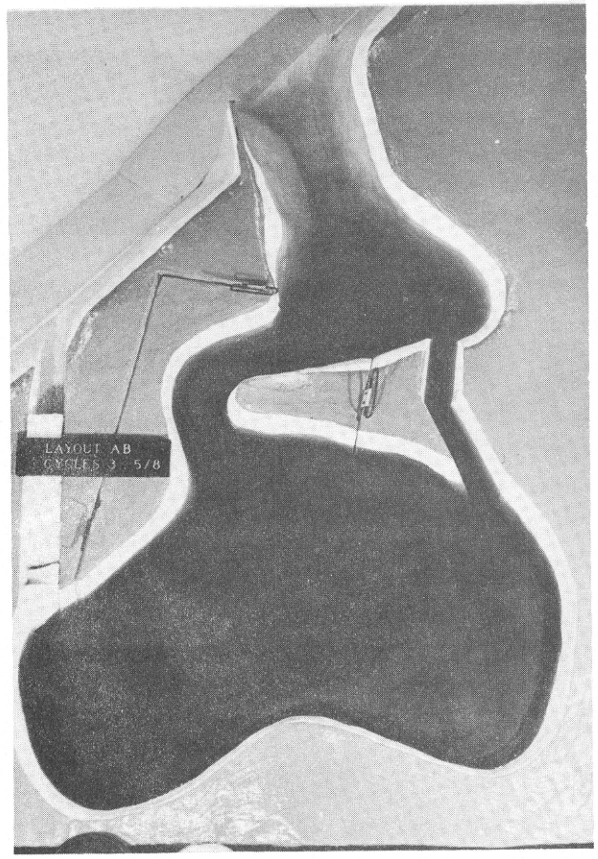

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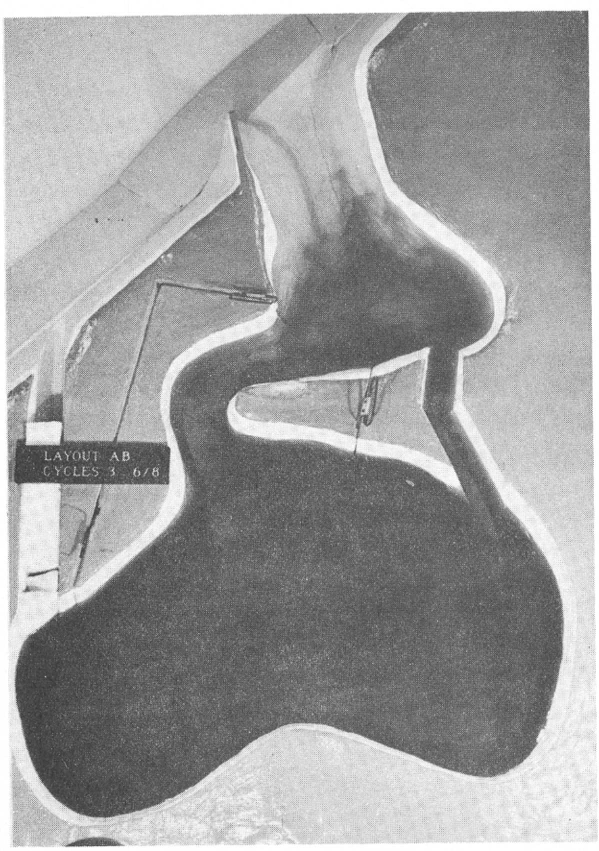

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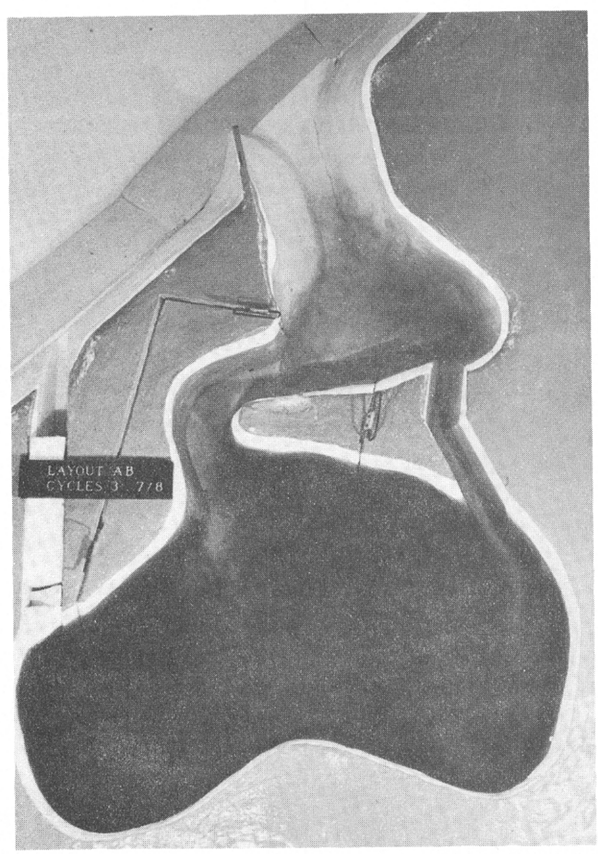

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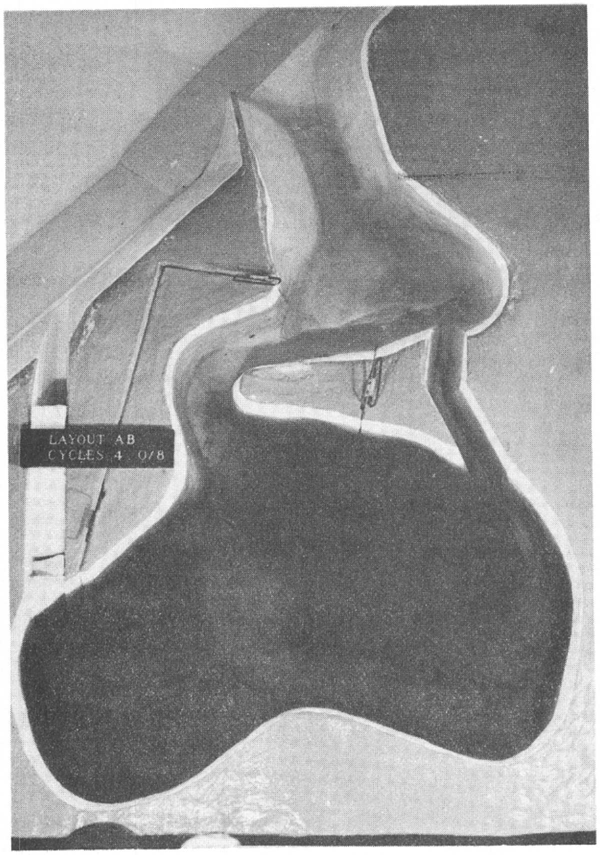

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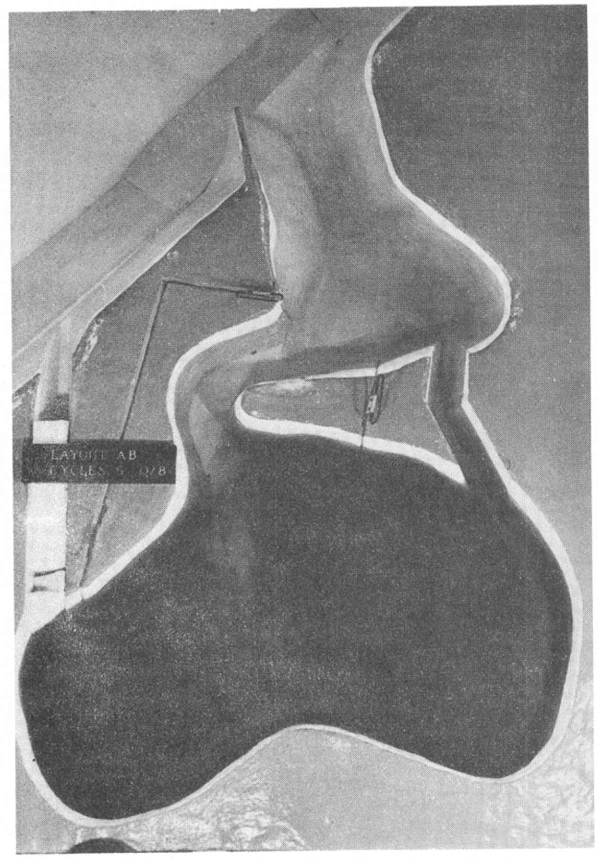

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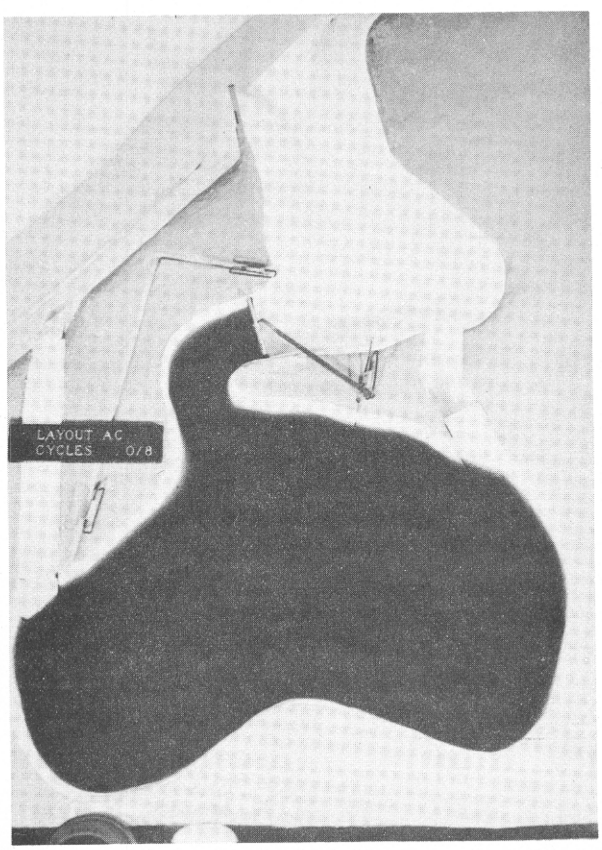

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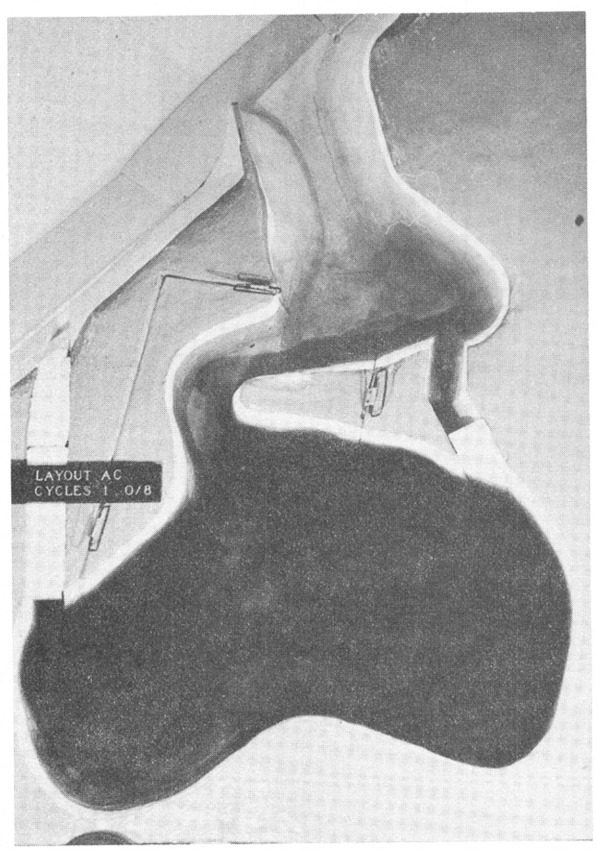

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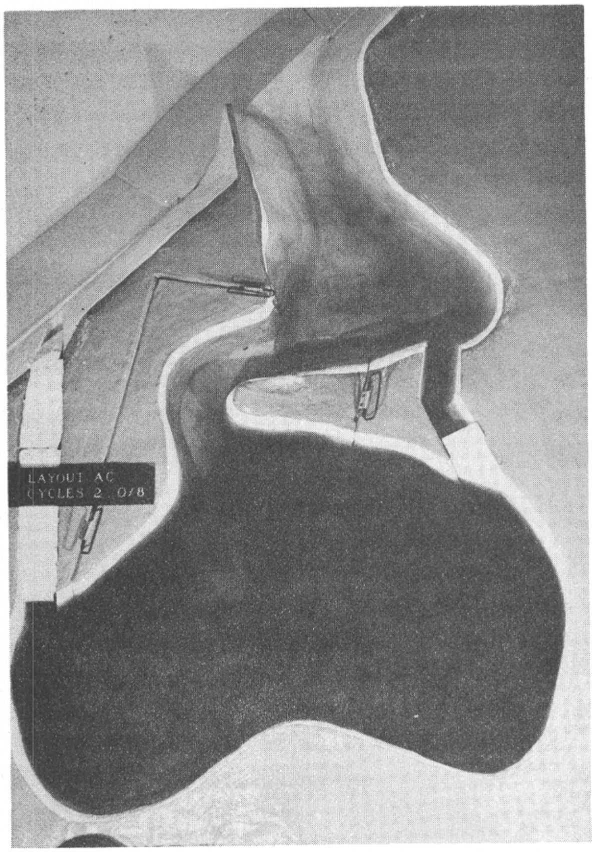

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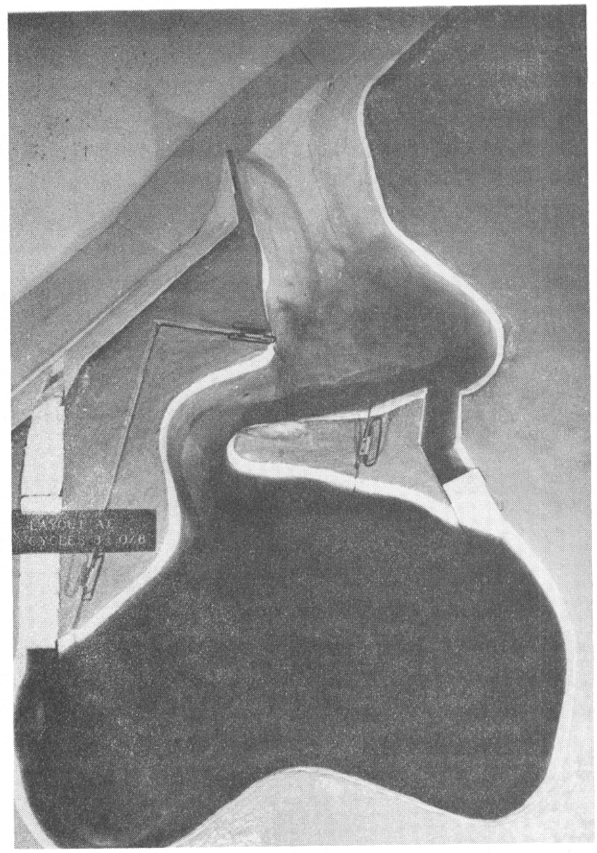

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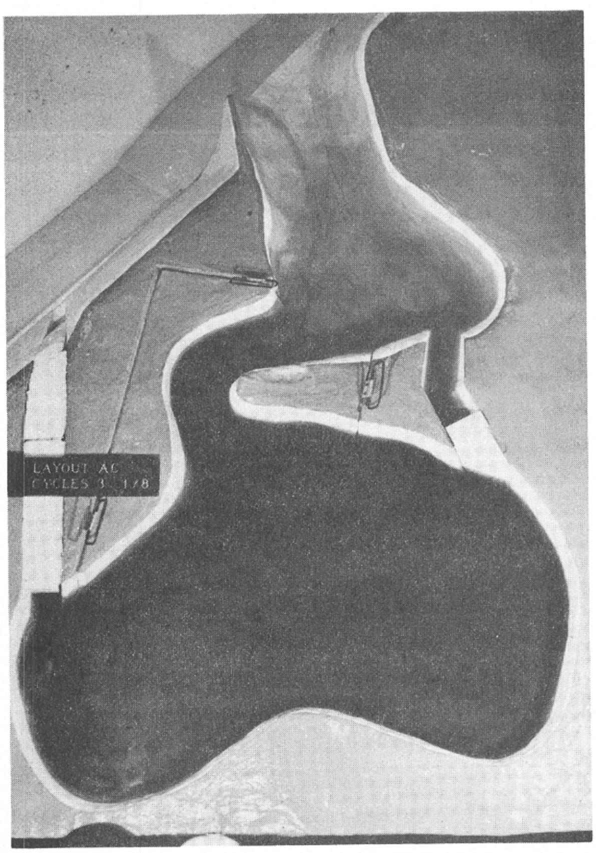

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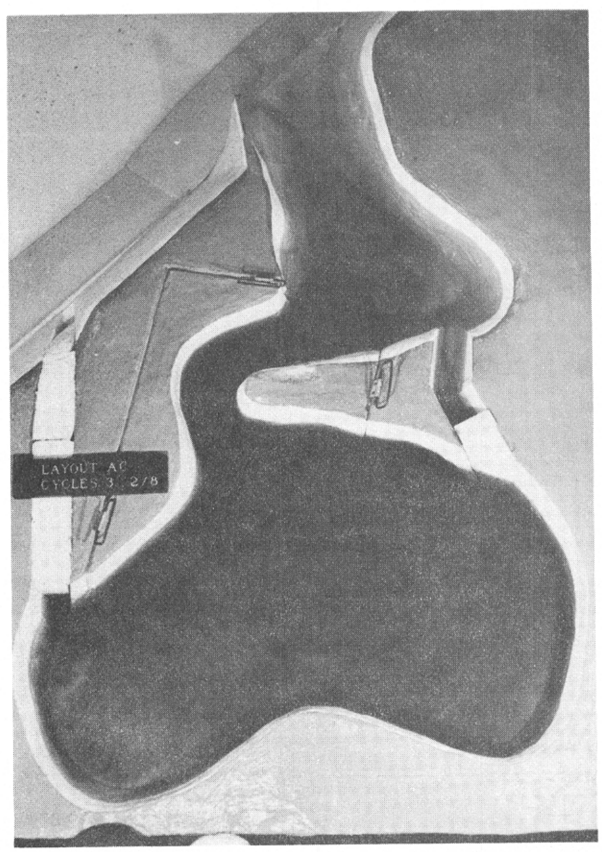

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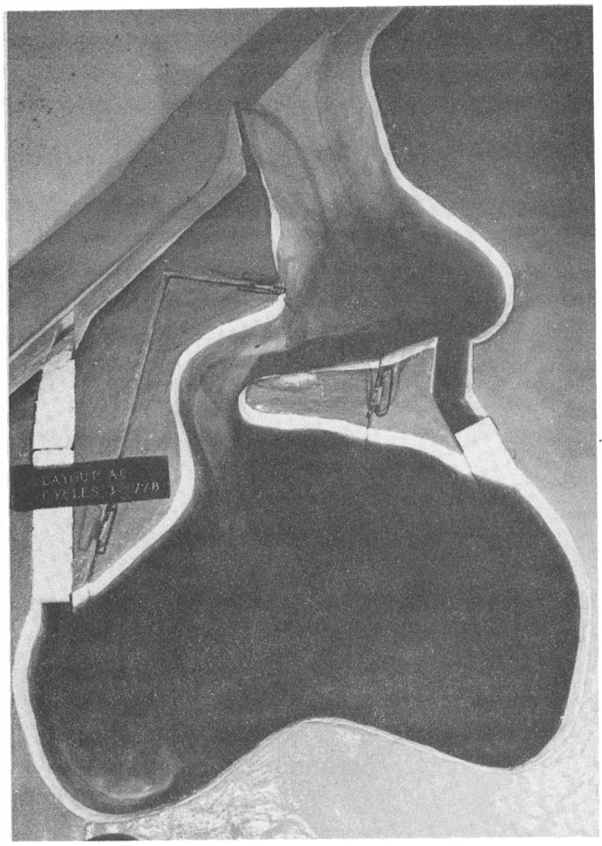

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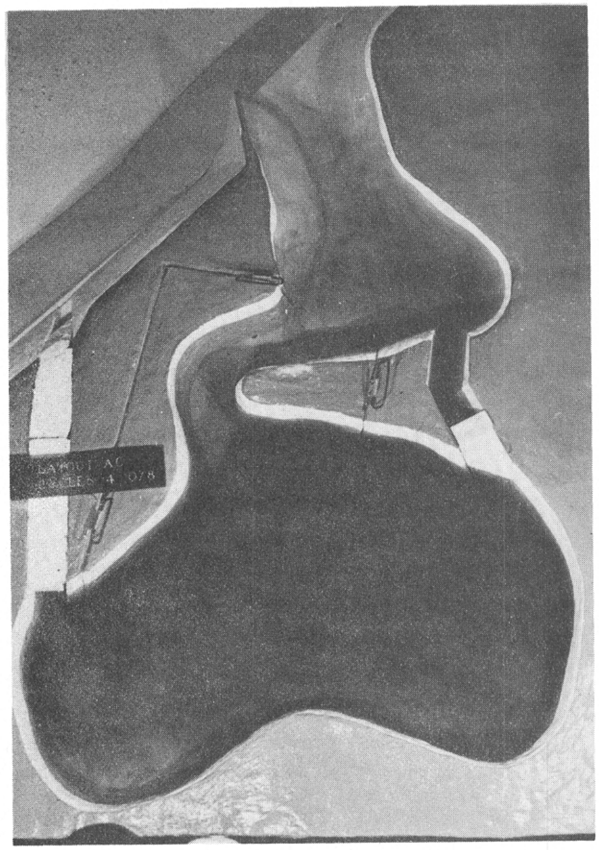

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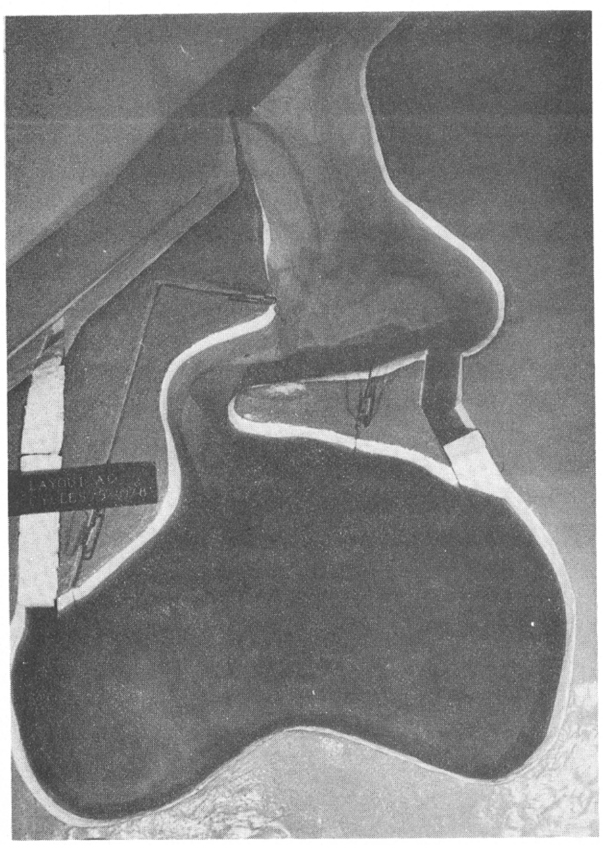

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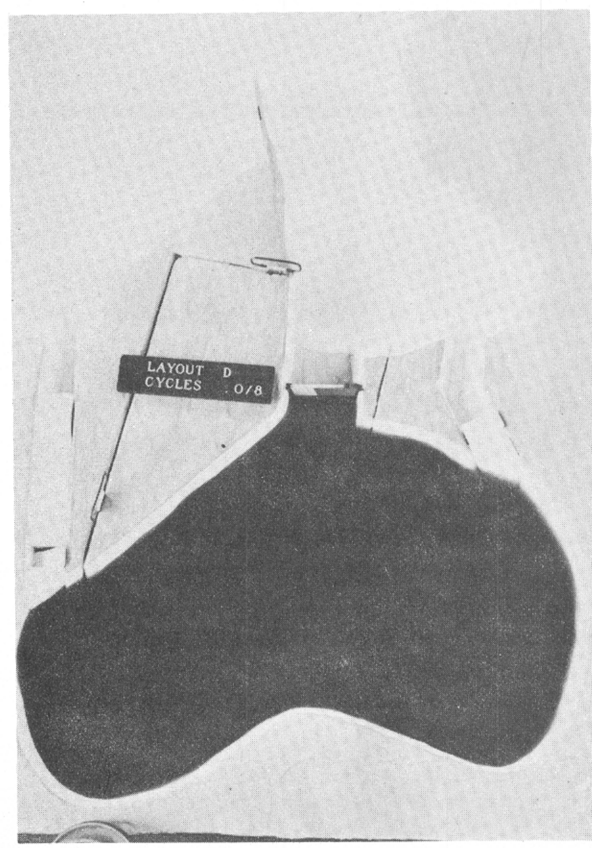

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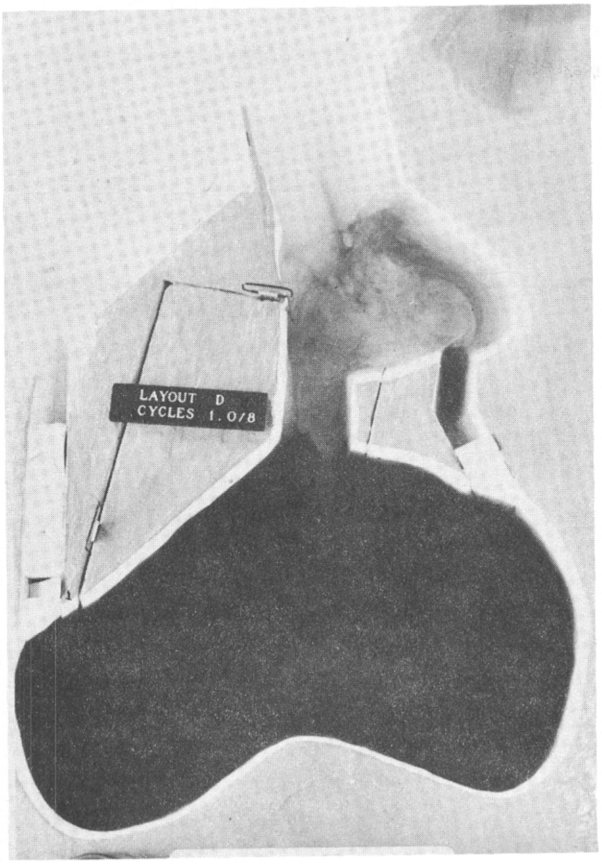

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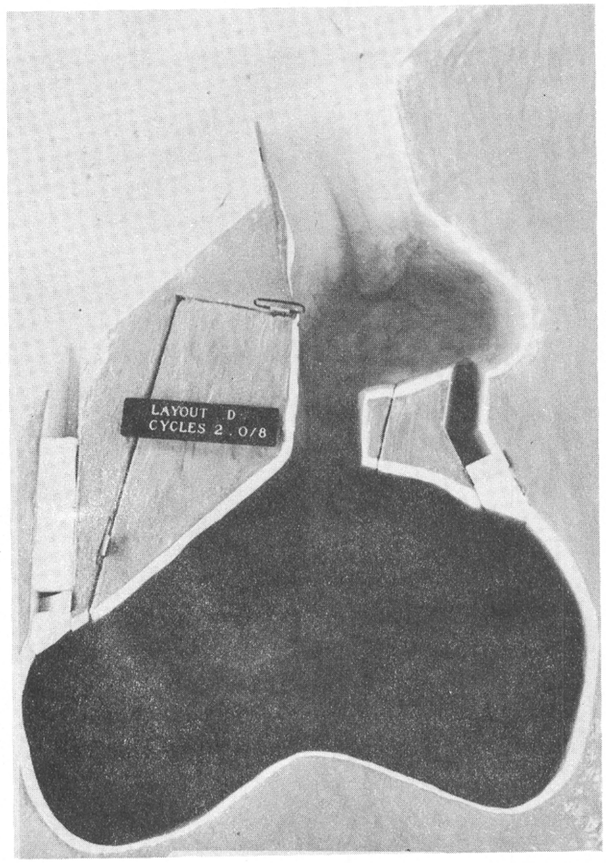
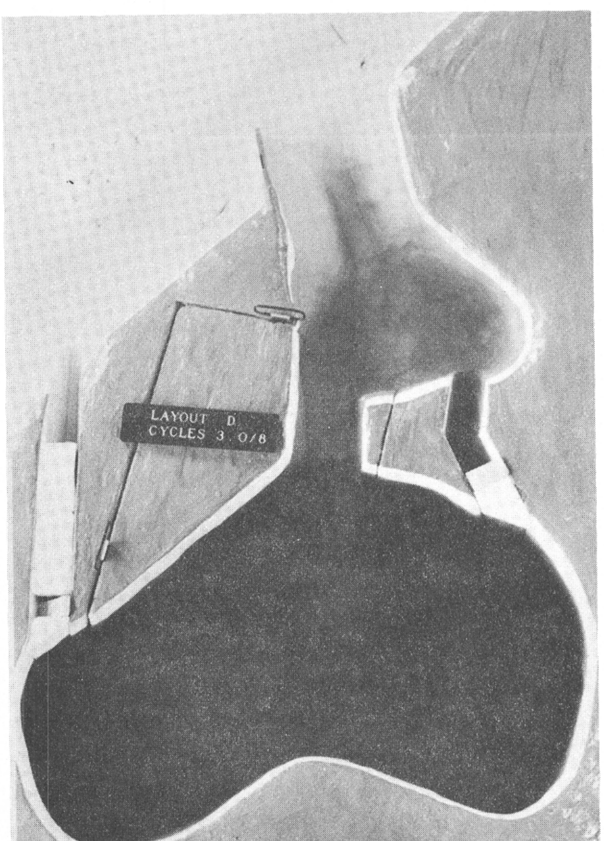


Figure 7c



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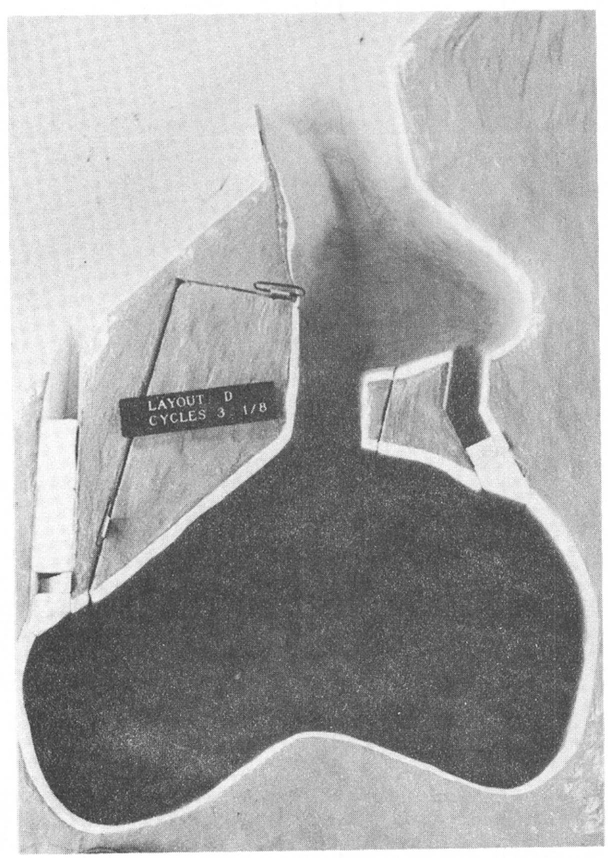

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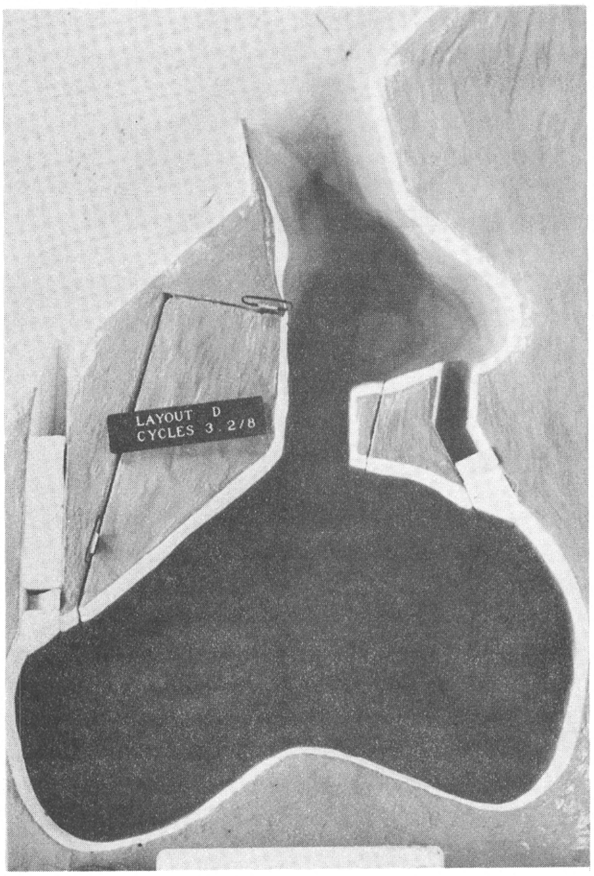

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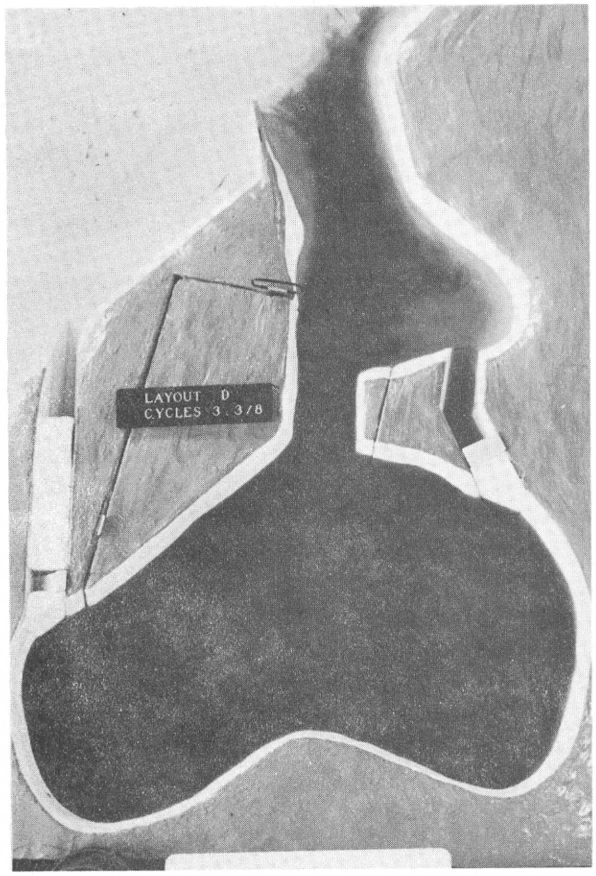


Figure 7g

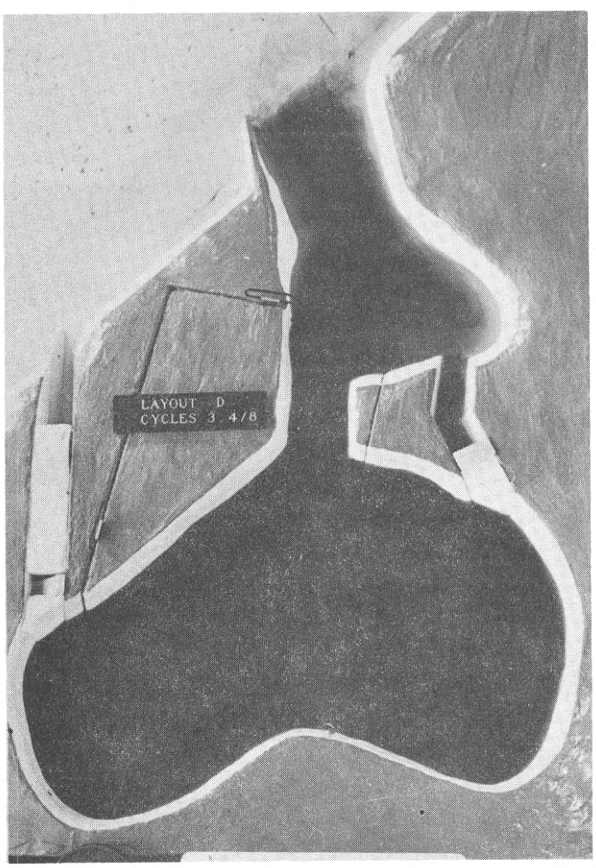


Figure 7h

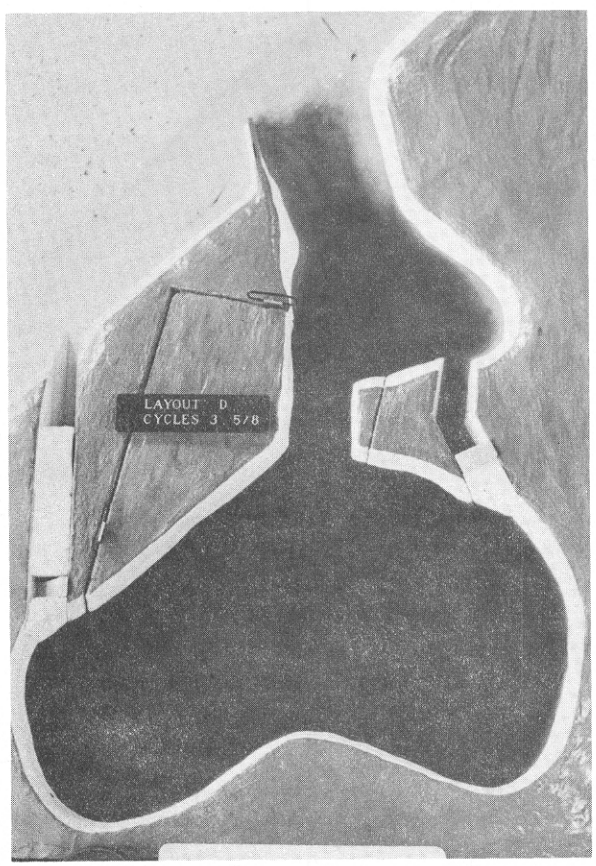


Figure 7i

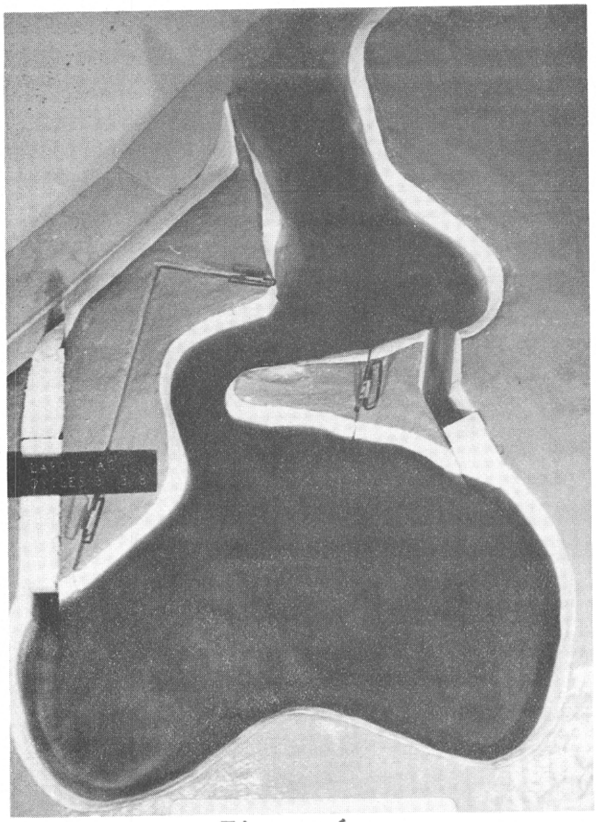
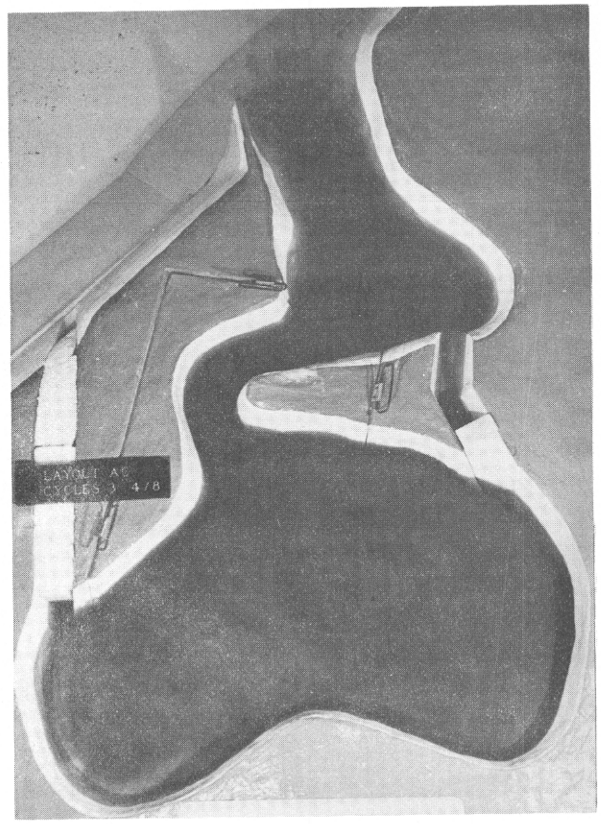


Figure 6g



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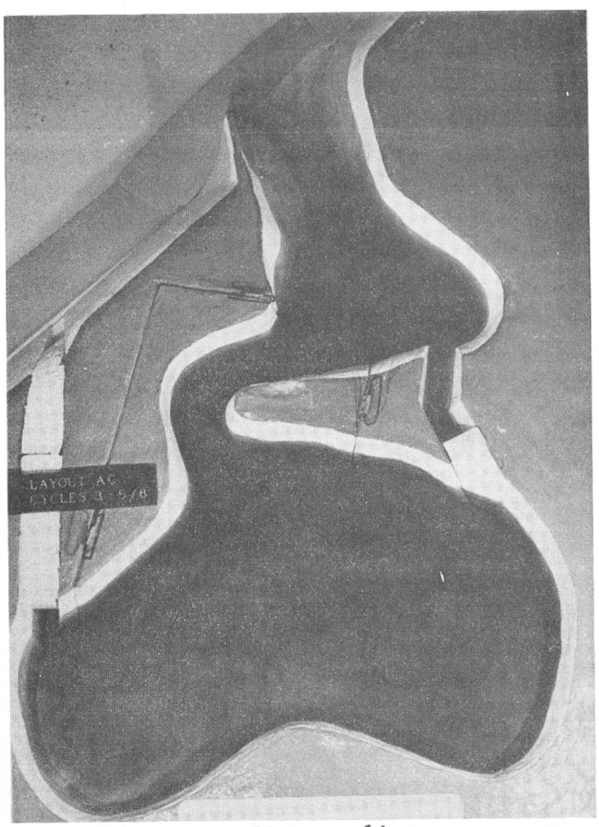
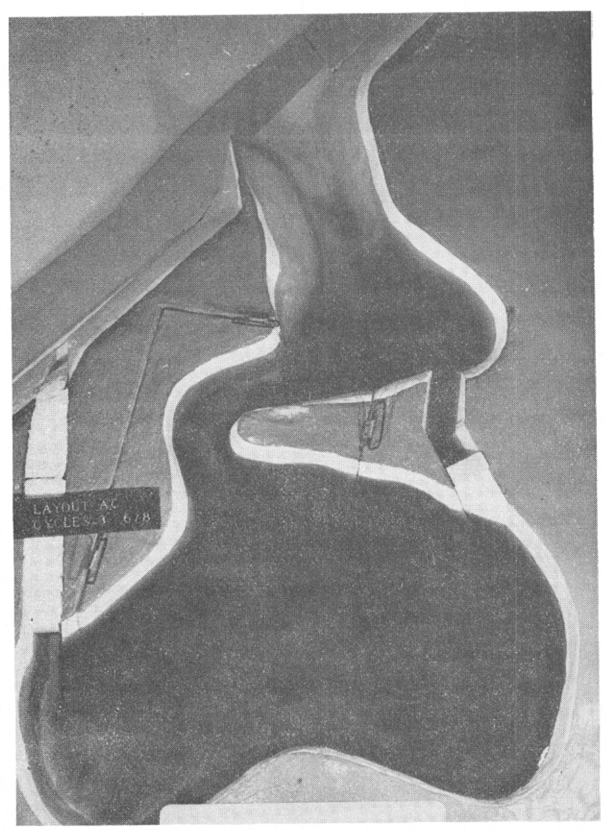


Figure 6i



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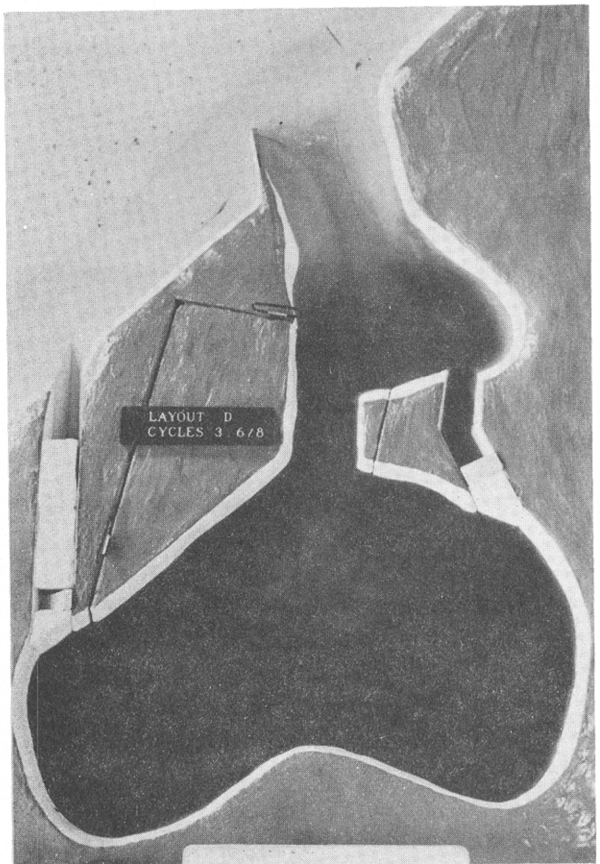

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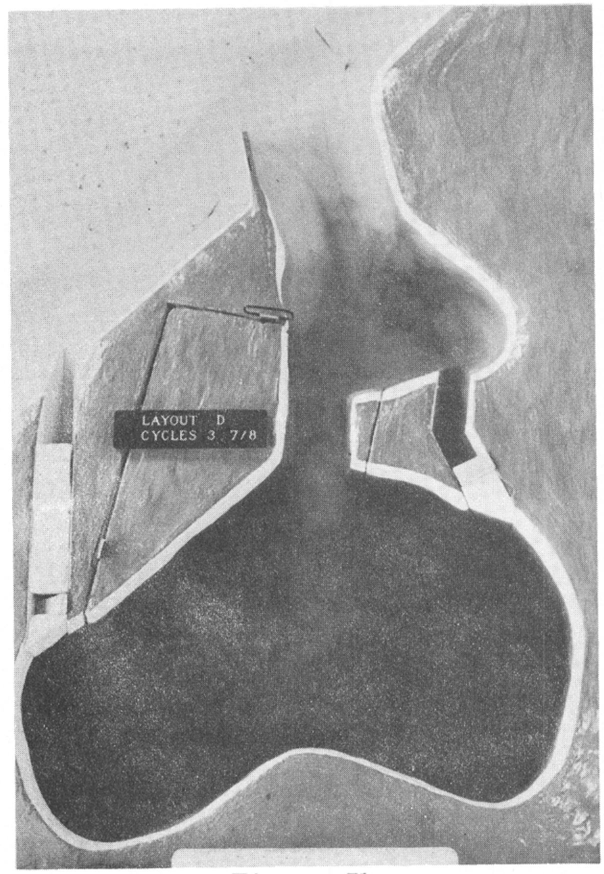

Figure 7k

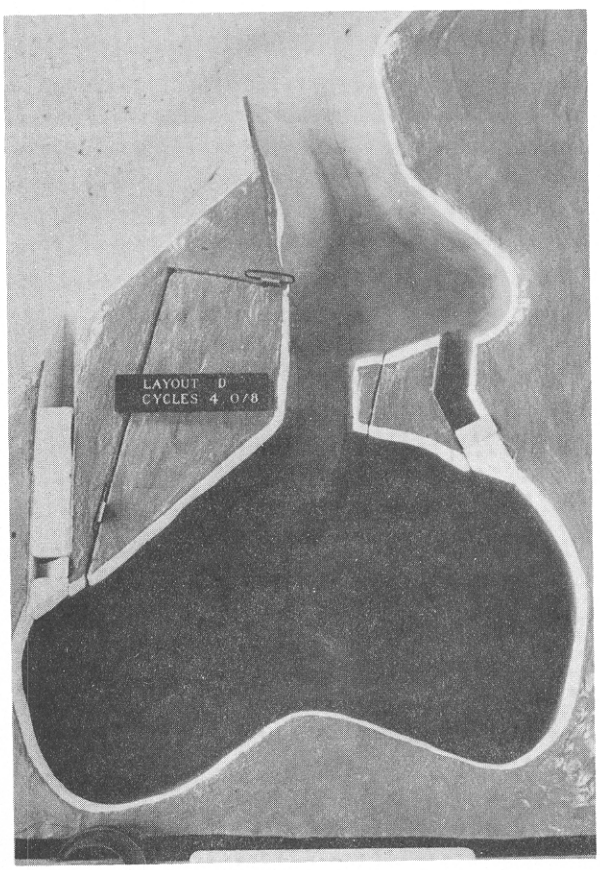

Figure 7l

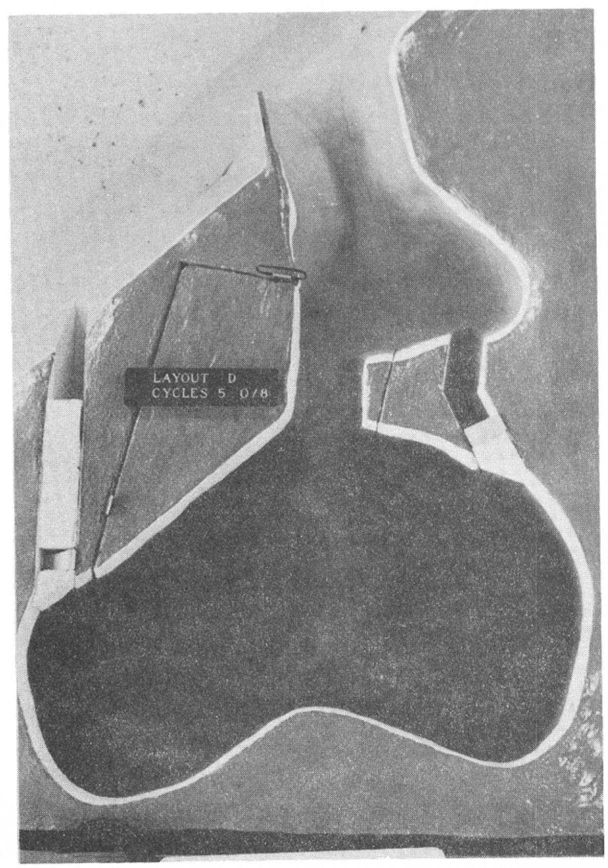

Figure 7m