ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
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Final Report

TESTS OF A FLOW SPREADER FOR A PAPER MACHINE

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Project 2454

WEST VIRGINIA PULP AND PAPER COMPANY
CHARLESTON, SOUTH CAROLINA

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SUMMARY

From studies at reduced scale conducted at The University of Michigan, a cross-flow spreader has been developed for which the distribution of flow is remarkably uniform. The flow enters the spreader from one side and is deflected as it passes through a perforated plate. Of the various elements studied, only the placement of splitter vanes immediately downstream from the plate had a marked effect. By their installation, an otherwise very poor distribution of flow was turned into a very good one.

Conditions of flow upstream of the perforated plate had only secondary effects on the distribution of the efflux. Tests with adjustable vanes in the return bend indicated that the uniformity was not affected significantly by the distributions of velocity and pressure in the approach flow. Regulation of the amount of flow which was by-passed changed the flow only locally, and that by a small amount. Of the two plates tested, results for the thinner plate were slightly, but consistently, more uniform than were those for the thicker one. The width of the opening at the outlet and the spacing of the splitter vanes are probably related in such a way that the wider the opening the less stable the flow and the larger the number of splitter vanes required. For the opening of 3.6 inches (on the model), good results were obtained with ten vanes.

ANALYSIS OF FLOW

The roles of the various parts of the spreader need to be understood in order that the results of the experiments can be interpreted. Several conceptions held at the beginning of the investigation were revised on the basis of observed instabilities of flow and other unexpected results. Perhaps the most surprising result was the predominance of certain characteristics of flow downstream from the plate and the consequent lesser importance of the characteristics of flow upstream. This point is emphasized because it changed the focus of the tests and led to a revision of statements made in conversation and correspondence between members of the staff of the West Virginia Pulp and Paper Company and The University of Michigan.

The original concept of a uniform stream flowing at an angle toward a perforated plate and being uniformly deflected was maintained throughout the study. The primary characteristics of the system were the distributions of velocity and pressure upstream from the plate, the amount of flow by-passed, the shape of the holes and their relative open area, and the geometry of the converging section downstream from the plate. Of these, the first and the third were studied sufficiently to reach conclusions. By contrast, the thickness of the plate was the only characteristic of the plate or holes which was varied.

Early failures were first attributed to improper approach flow. Installation of adjustable vanes, velocity probes, and piezometer taps provided a means of observing and controlling this flow. Although the results remained quite unsatisfactory, an important fact was noted. The flow through the plate with the outlet submerged and with the various jets discharging freely into the air appeared to be much more uniformly distributed than did the submerged flow. Also, the free jets were vertical whereas fine air bubbles in the submerged flow indicated that the streamlines were inclined as much as 20° to 30° from the vertical with the outlet submerged.

The cause of the early failures was finally concluded, and later proven, to be the instability of the flow downstream from the plate. The simultaneous expansion of the small jets and the contraction of the side walls could take place, apparently, in various ways; the flow at the supply side being markedly nourished at the expense of that on the by-pass side. Insertion of the splitter vanes changed the cross section in this region from a very long rectangle to a number of approximately square sections and brought about the stable distribution which was the goal of the investigation.

Limitations on time and funds for the primary phase of the study restricted tests on other factors which are less predominant but which may still have effects worth exploring. Conditions upstream of the plate were repeatedly shown to have only minor effects; yet, the pressure and velocity distribution probably should be kept as nearly uniform as is practicable. The by-pass will doubtless serve to keep the plates clean, but only a small fraction of the flow, say five percent, is likely to be required. The effects of chamfering the holes and of varying the relative total open area have not been explored. Finally, the complex interrelationship between the dimensions of the holes, the number of splitter vanes, and the angle of convergence of the outlet section can only be conjectured on the basis of the limited tests conducted. A good and stable distribution has been obtained, but numerous other possibilities which may be simpler to construct and equally as good have not been tested.

Use of a pulp suspension rather than water may introduce complications which are unpredictable on the basis of the model tests with water. Also, the use of a small model led to a reduced Reynolds number. These effects are probably small, but substantiation with pulp at a large scale would be desirable. Further tests, at small scale, of the originally troublesome instability would also lead to a better understanding of the phenomenon and to greater confidence in the applicability of the findings.

EXPERIMENTATION

DESCRIPTION OF EQUIPMENT AND MODELS

The models were tested in the Hydraulics Laboratory of the Civil Engineering Department at The University of Michigan. The water supply was taken from a constant head tank with a static head of 9 feet at the spreader. The available static head and the pumping capacity of the circulating system determined the selection of the size of the models. The model was designed to provide a discharge velocity about equal to that of the prototype. The discharge was such that a scale factor of about 1/5 was feasible. Accordingly, a standard 6-inch pipe was used to represent the 28.8-inch supply line, so that the scale factor was 0.210.

The discharge from the models was collected in an intermediate open tank from which it was led to a volumetric basin. The basin is a part of the permanent laboratory equipment. That part of the flow which was by-passed was carried through a separate line to a smaller portable weighing tank.

The model layout, including general arrangements of the two basic models tested, is shown in Drawing 2454-01. Because of the arrangement of the laboratory facilities, the model spreader was designed to discharge downward even though the direction of flow is upward in the prototype. Measurements of the velocity distribution were thereby facilited also. The original model was designed and built according to Drawings S-4916 and S-4917 (WVPP designation) submitted by the sponsor. Drawing S-4917 gives the details of two different schemes of spreader design, scheme B based on a perforated plate as a spreader device being the only one tested during this investigation. Small deviations were made in the design of the model from that proposed. These changes are minor and should have no effect on the flow distribution in the spreader. One possibly important exception, however, is the design of the perforated plate. The action of the countersunk holes, as proposed for the prototype, was unknown and probably detrimental, so plates with straight holes were tested. For this investigation two plates with straight drilled holes were used in the tests, the thin plate corresponding to that proposed, the thick plate being nearly twice as thick.

The design of the second and considerably modified model was based on the interpretation of the results obtained with the original model. It incorporated the following changes:

1. The flow boundary at the upstream end of the perforated plates and at the inlet to the by-pass was made smooth and devoid of any abrupt changes.

2. The by-pass opening was decreased to 1/4 inch in the direction normal to the plate.

3. The divergent transition section was placed upstream from the bends, and the cross-sectional area ratio was reduced from 2.6:1 to about 2:1. The cross section of the flow was held constant from the downstream end of the transition section to the upstream edge of the spreader.

4. The return bend consisted of two mitre bends with five turning vanes. Initially, the turning vanes were fixed. Later, the angular position of these vanes was made adjustable (see Fig. 16).

5. The model was lowered into the intermediate collecting tank so that the outlet could be submerged during the tests.

6. Two splitter plates aligned with the flow and normal to each other were installed in the transition section upstream, extending over its total length.

Additional modifications of the model were installed for some of the tests and removed for others:

1. Perforated plates were installed at various points across the duct upstream of the spreader. These plates had 3/8-inch-diameter holes and reduced the open area of the cross section by 50 percent.

2. Vertical splitter vanes in the tapered section were installed below the perforated plates in the modified model.

3. A tapered section with an outlet width of 3.6 inches (compared to the original design of 2.6 inches) was built and tested.

All velocity measurements were made with stagnation tubes inserted into the flow. The tubes were made from copper tubing (1/32 inch ID). In the case of the modified model, the static pressure was taken into account by using the water level in the intermediate collecting tank as an indication of the static head. The tube openings were always placed just at the level of the spreader opening. Readings from the original model were made from the free jet where the static reference pressure was atmospheric.

Several methods of recording the stagnation pressures were used. The most accurate readings were made with a micrometer and hook gage which gave the pressure head to within 0.002 inch. Measuring with this device was time consuming, however, and it was found sufficiently accurate to read from an ordinary one-hundred scale with an accuracy of 0.02 inch. The micrometer system was used occasionally as a check.

The stagnation tubes were used to determine variations in the velocity along the spreader outlet (cross-machine direction). The rate of discharge was determined from measurements of the time required to fill a known portion of the volumetric tank. Two predetermined water levels were indicated by an electronic eye, while the model discharged continuously into the tank. Simultaneously, and over the same time interval, the by-pass flow was discharged into the portable weighing tank and measured. Because the local discharge from the spreader depends on both the velocity and the width of the opening, the latter dimension was measured with a micrometer. The maximum variation in width was found to be 0.02 inch.

The distribution of the flow in the duct immediately upstream of the spreader was also determined by means of a stagnation tube. In this case the velocity head was evaluated from the difference in readings obtained with the tube pointing alternately upstream and downstream to eliminate the effect of the static pressure. The difference was multiplied by a factor of 0.87 to obtain the velocity head. The magnitude of this factor was determined from the known rate of discharge.

TEST PROCEDURES AND RESULTS

The testing sequence can be divided into two parts, tests with the original model and tests with the modified model. During the testing of the models, various components such as the perforated plates and the splitter plates were installed, rearranged, or removed, but once the modified model was installed the original model was never retested to determine its performance with components such as the vertical splitter vanes. This incompleteness is not important, however, because the modified model incorporates the main physical features of the original model, except for several improvements as mentioned under the model description. Results obtained with the modified model should therefore pertain also to the general problem of spreader design as outlined by the original plans.

TESTS WITH ORIGINAL MODEL

The original placing of the discharge opening above the collecting tank led immediately to the difficulty that the trapezoidal section did not flow full. Even after the flow at the outlet opening was obstructed sufficiently to force the tapered section to flow full, the individual jets from the spreader plates would reappear once the obstruction was removed.

To remedy this marked departure from prototype performance, a hinged plate was inserted along the back side of the tapered section and adjusted to provide various outlet widths, thus changing the angle of taper. It was found necessary to decrease the outlet openings to about one-quarter of its original size before all the air was removed and the section would flow full. Some trouble was caused by the suction of air into the flow below the perforated plate from behind the hinged plate and along the end plates of the tapered section. The air leakage was eliminated by the application of moulding clay among all joints.

After proper flow was established, the opening was traversed with the stagnation tube. The distribution of velocity was found to vary linearly along the outlet opening, being about seven percent higher at the downstream end than at the upstream end. A change in the amount of flow by-passed did not affect the distribution of flow; only the absolute magnitudes were altered. At both ends of the outlet violent rolling eddies sometimes appeared. These eddies may have been caused by the small offset between the perforated plate and the flow ducts upstream and downstream of the plate. The offsets were therefore removed by means of placing filler pieces above and below the spreader plates at both ends of the spreader, reducing its length by 3.6 inches. At the same time perforated plates were inserted across the duct at both ends of the transition piece upstream. The flow distribution was altered by these changes in such a way that the greater discharges were now at the upstream end of the outlet. Once again, the amount of by-pass did not change the velocity distribution materially. Furthermore, the quantity of flow had no effect on the distribution at the spreader outlet. This indicated that the Reynolds number of the flow was probably not an important variable.

Figures 1 and 2 show the results from the tests with the original model. All of these tests were run with the thick perforated plate installed. Observations had indicated that this plate did a better job of turning the flow, the jets from the thin plate tilting slightly in the downstream direction.

It was difficult to explain the reversal of the flow distribution experienced in the preceding test series, especially since several changes had been incorporated simultaneously for the sake of expediency. An analysis was made of the velocity head above the perforated plate which showed the velocity head to be decreasing in the downstream direction. Neglecting frictional losses, this would indicate a higher static pressure above the perforated plate at the downstream end. Since the flow distributions for some tests ran counter to this indication, pressure taps were inserted in the side immediately above the spreader plate. Readings of these pressure taps showed that the static pressure was practically constant, only the pressure at the downstream end being affected by the by-pass.

So far, the failure of the by-pass to provide means of flow control had been established, but the main problem of obtaining a uniform distribution of velocity still remained. This appeared to be a function of the geometry of the spreader, so a decision was made to proceed with the modified model.

TESTS WITH MODIFIED MODEL

The first test series with this model clearly indicated that some new and undesirable conditions had been introduced. As shown in Fig. 3, the velocity was much greater for the upstream end of the outlet, a condition that could not be corrected by the use of perforated plates in the duct. Because the outlet opening was now submerged, no artificial contraction in the trapezoidal section was necessary. The static pressure above the perforated plate decreased somewhat in the downstream direction, but the maximum difference was only a few percent. Figure 4 shows the velocity distributions obtained from the duct. The correspondence between the flow in the duct and the distribution of the discharge indicated an interdependence between the two. Adjustable vanes were therefore installed in both bends so that a wide range of flow distributions in the duct could be obtained. Several tests were run with different settings of the vanes. Figure 5 shows the results from two typical tests, one with a velocity distribution in the duct heavy toward the top of the duct, i.e., the opposite of previous distributions, the other being essentially uniform. All results showed clearly that the turning vanes were unable to correct the bad velocity distribution in the spreader.

All indications pointed to the ineffectiveness of control measures upstream of the spreader plate, and focused attention on the flow conditions downstream of the plate. Tiny air bubbles suspended in the water provided an indication of the streamlines if illuminated by a strong light. A look at the flow revealed that the flow lines instead of being vertically down were slanted toward the upstream end, creating eddies at both end plates. Figure 10 shows the character of this flow. To eliminate the formation of this undesirable pattern of flow, a set of vertical splitter vanes, extending from approximately 1/8 inch below the perforated plate to the discharge opening, was built and installed in the tapered section. Three sets of splitter vanes were tested with five, eight, and ten vanes, respectively. In all cases the vanes were uniformly spaced.

Figure 6 shows the results obtained for the three splitter spacings and with the thick spreader plate. These show a tremendous improvement compared to previous results, and they indicate that the spreader plate is performing satisfactorily. The source of the trouble was thus found to be the instability of the flow below the plate. The deviations indicated in Fig. 6 are mostly due to eddies formed in each compartment between two splitter vanes. Figure 11 shows a typical flow pattern in such a compartment.

Figure 7 shows the results obtained with the splitter vanes, but with the thin plate interchanged with the thick spreader plate. It is noted that the thin plate gave, in general, better results than the thick. One reason for this may be the fact that the eddies are smaller and in some compartments have vanished completely. Any attempt to explain the behavior of the flow below the perforated plates, however, will have to be postponed until further detailed studies have been made on the action of the spreader.

A fairly complete test series was made with the modified model in which the wider-opening, tapered section was used. The increase in opening width was 38 percent over the original value. The purpose of these tests was to determine whether the sudden enlargement at the joint between flow spreader and head box could be avoided. Figure 8 shows the test results obtained with the thick perforated plates. The two tests recorded are for no splitter vanes and ten splitter vanes, respectively. Figure 9 shows the velocity distributions for three different flow conditions, ten splitter vanes being used in all cases and the thin perforated plate installed in the spreader. The graphs show that the by-pass did influence the flow at the upstream end for this setup. This phenomenon was observed in one test only and cannot be readily explained. It may have been caused by a change of secondary flow in the duct. Furthermore, it was established that the turning vanes were unable to destroy a good flow distribution in the spreader unless they were shifted so far as to obstruct partially the flow in the duct.

ACKNOWLEDGMENTS

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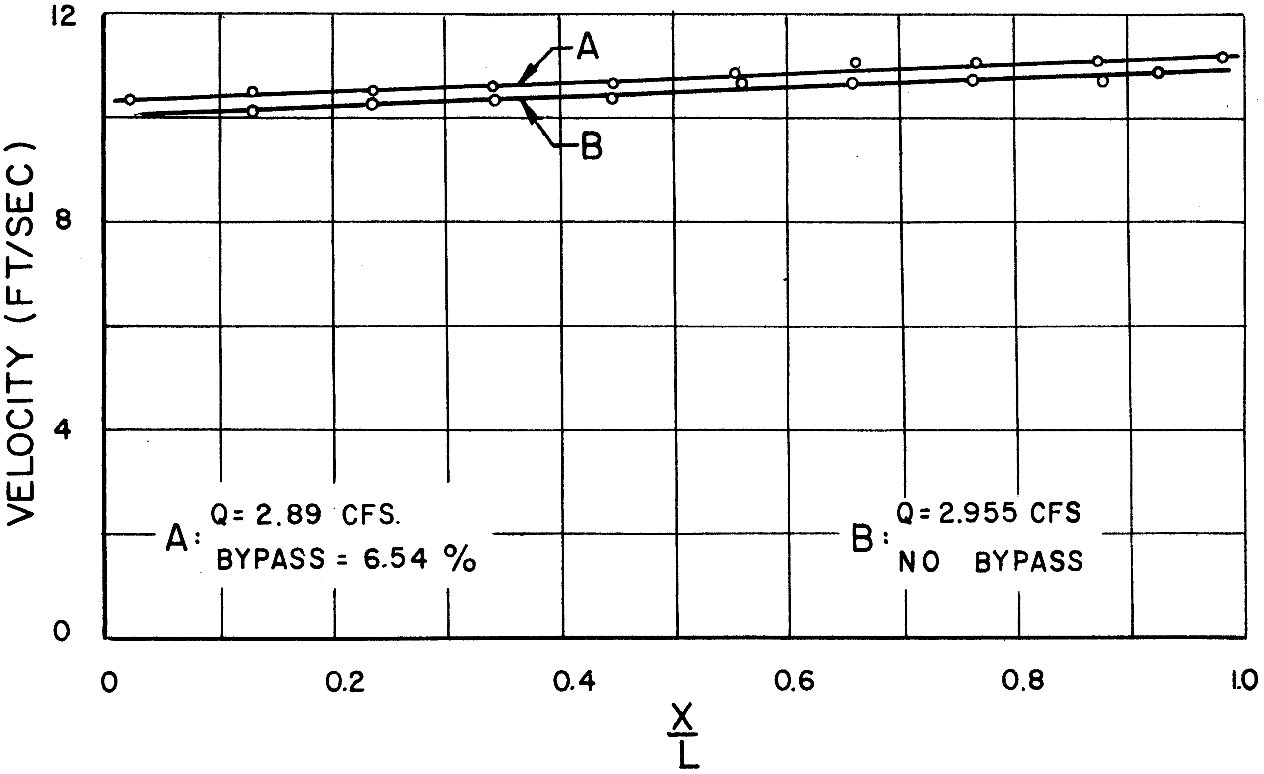


Fig. 1. Distribution of velocity along outlet of spreader for thick perforated plate (original model with contracted outlet).

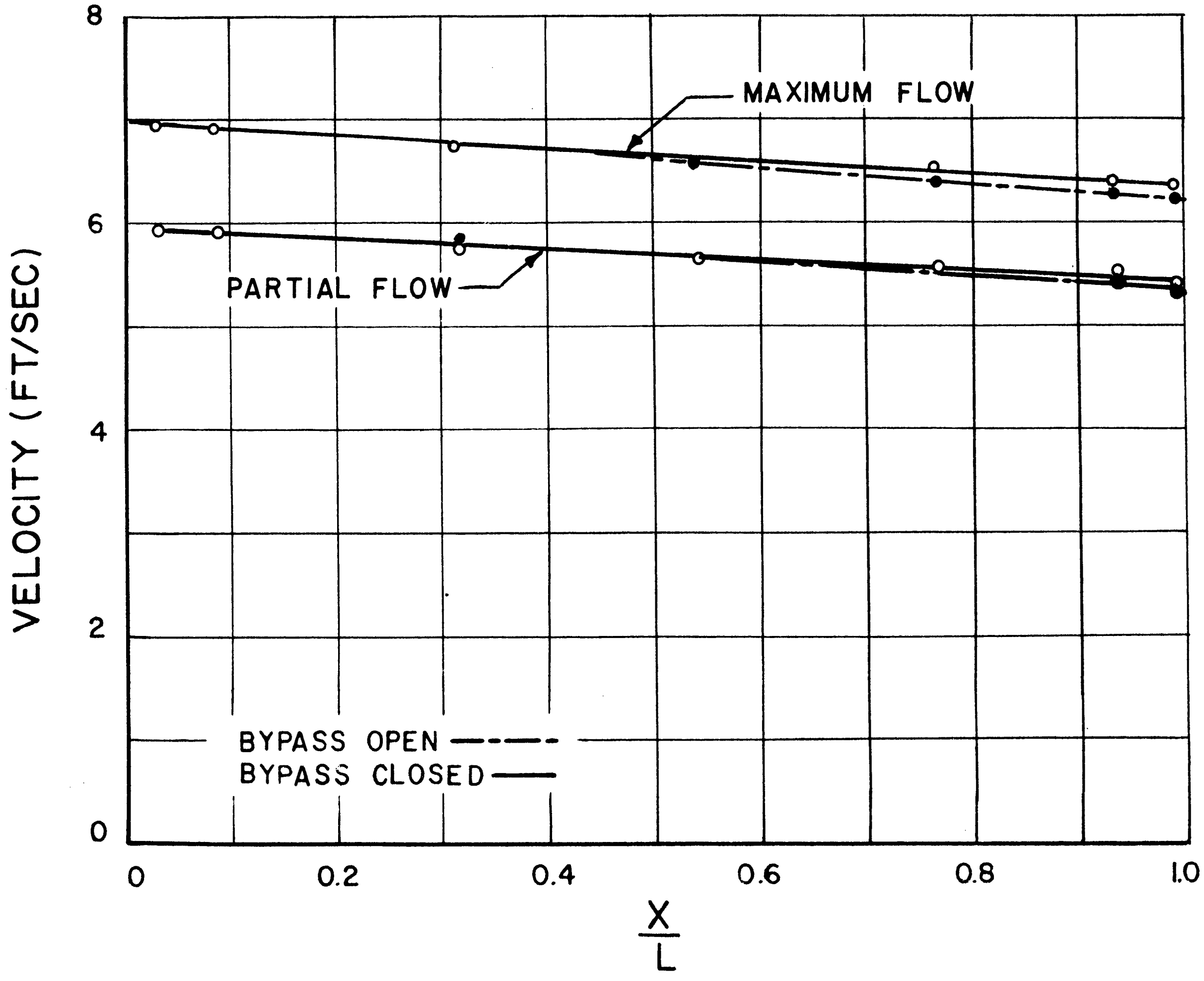


Fig. 2. Distribution of velocity along outlet of spreader for original model with perforated plates in the duct.

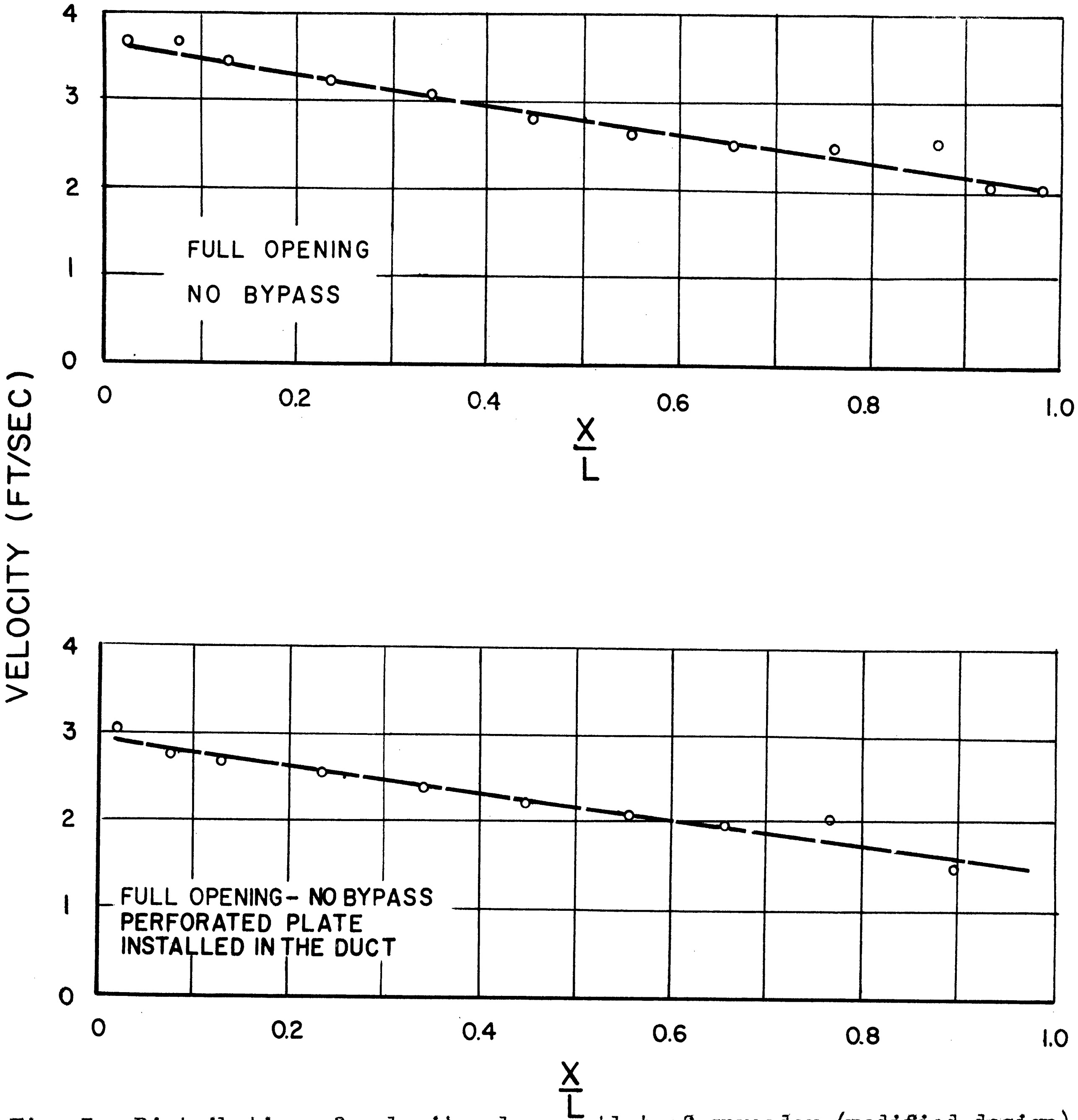
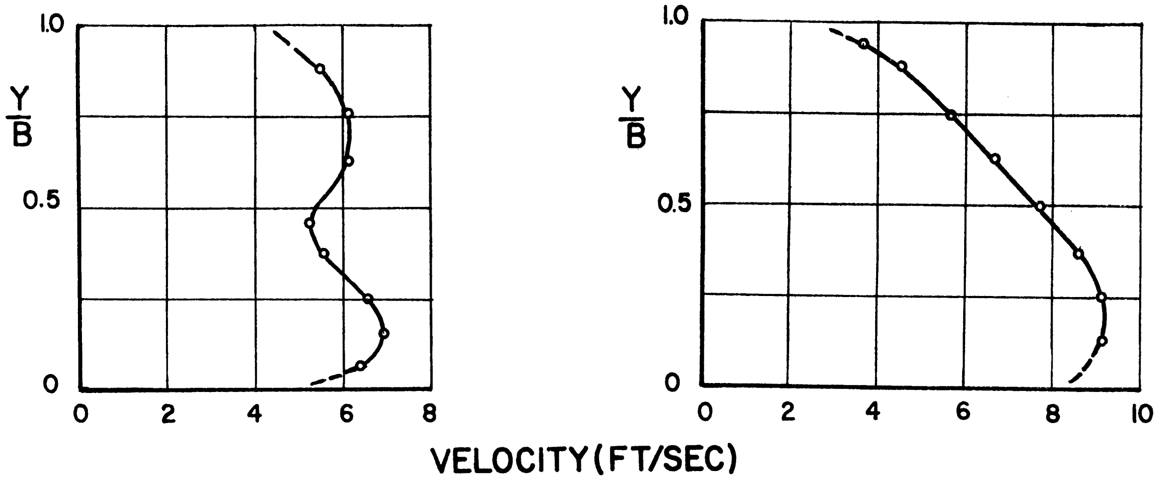
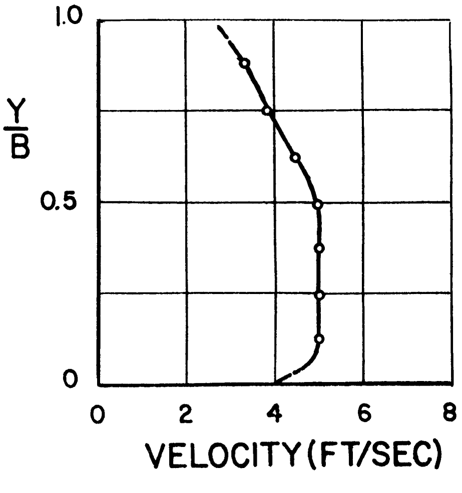


Fig. 3. Distribution of velocity along outlet of spreader (modified design).



CASE I

CASE II



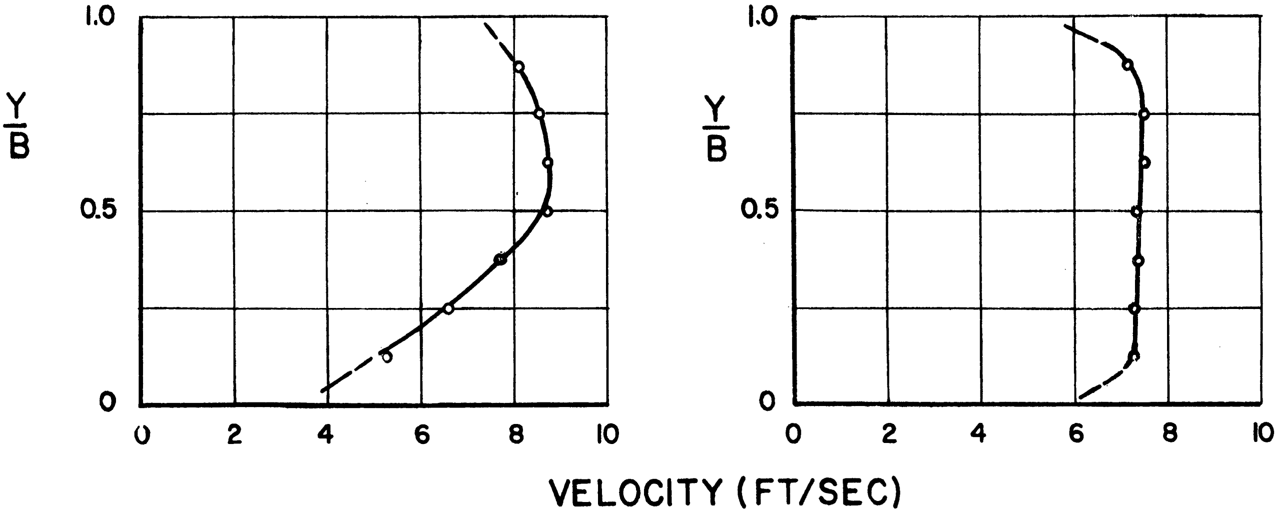
CASE III

CASE I: BOTH PERFORATED PLATES INSTALLED ACROSS THE DUCT.

CASE II: PERFORATED PLATES REMOVED.

CASE III: PERFORATED PLATE INSTALLED AFTER DIVERGENT SECTION.

Fig. 4. Distribution of velocity across the duct.



Distribution of velocity across the duct.

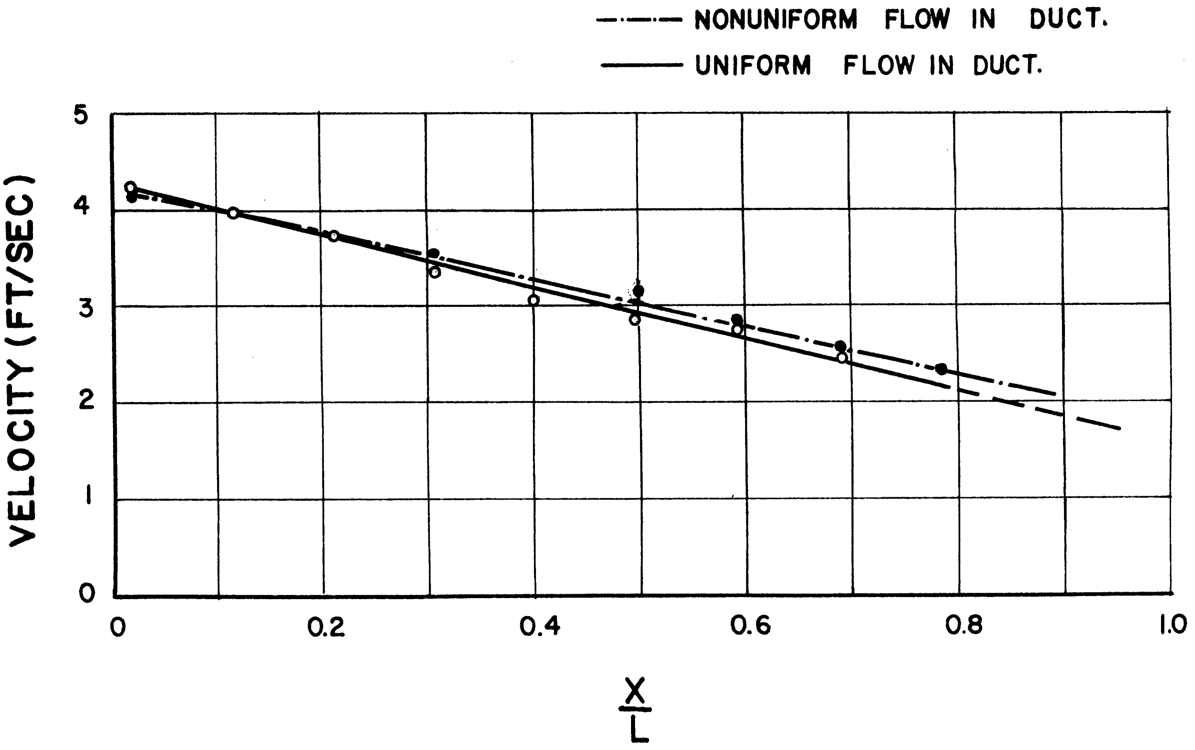


Fig. 5. Effect of the distribution of velocity across the duct on the distribution of velocity along outlet of spreader.

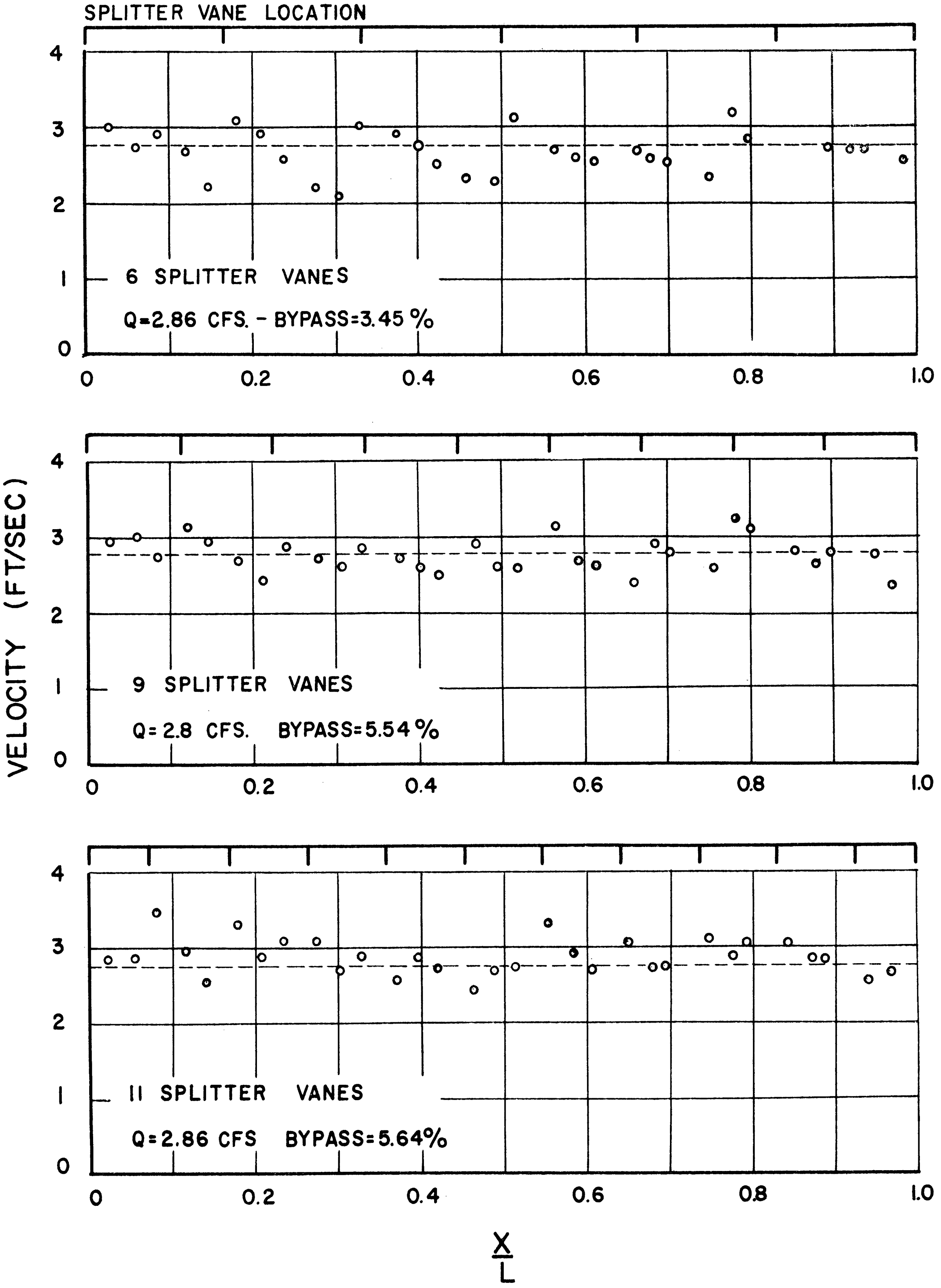


Fig. 6. Distribution of velocity along outlet of spreader for thick perforated plate (modified design).

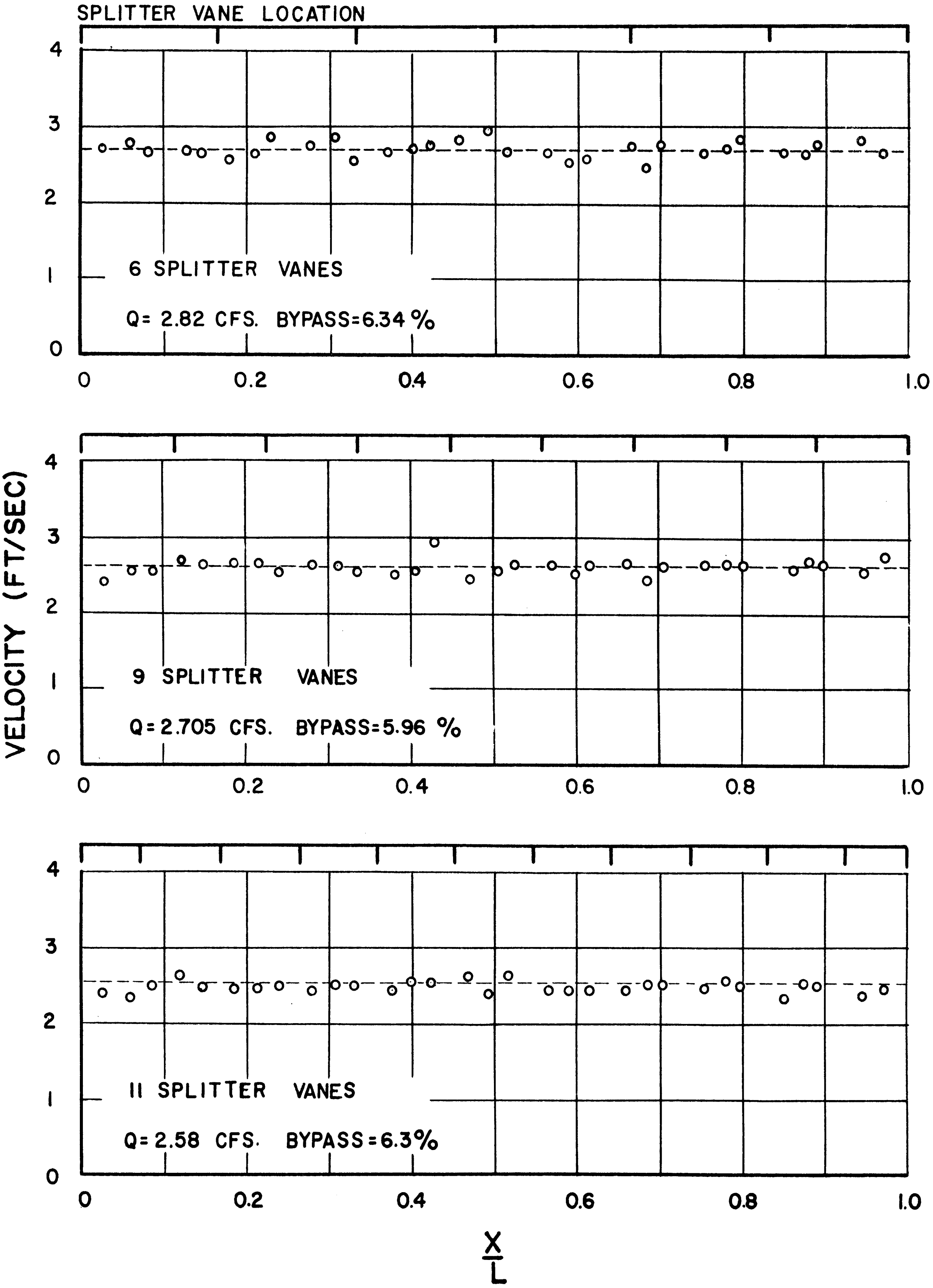


Fig. 7. Distribution of velocity along outlet of spreader for thin perforated plate (modified design).

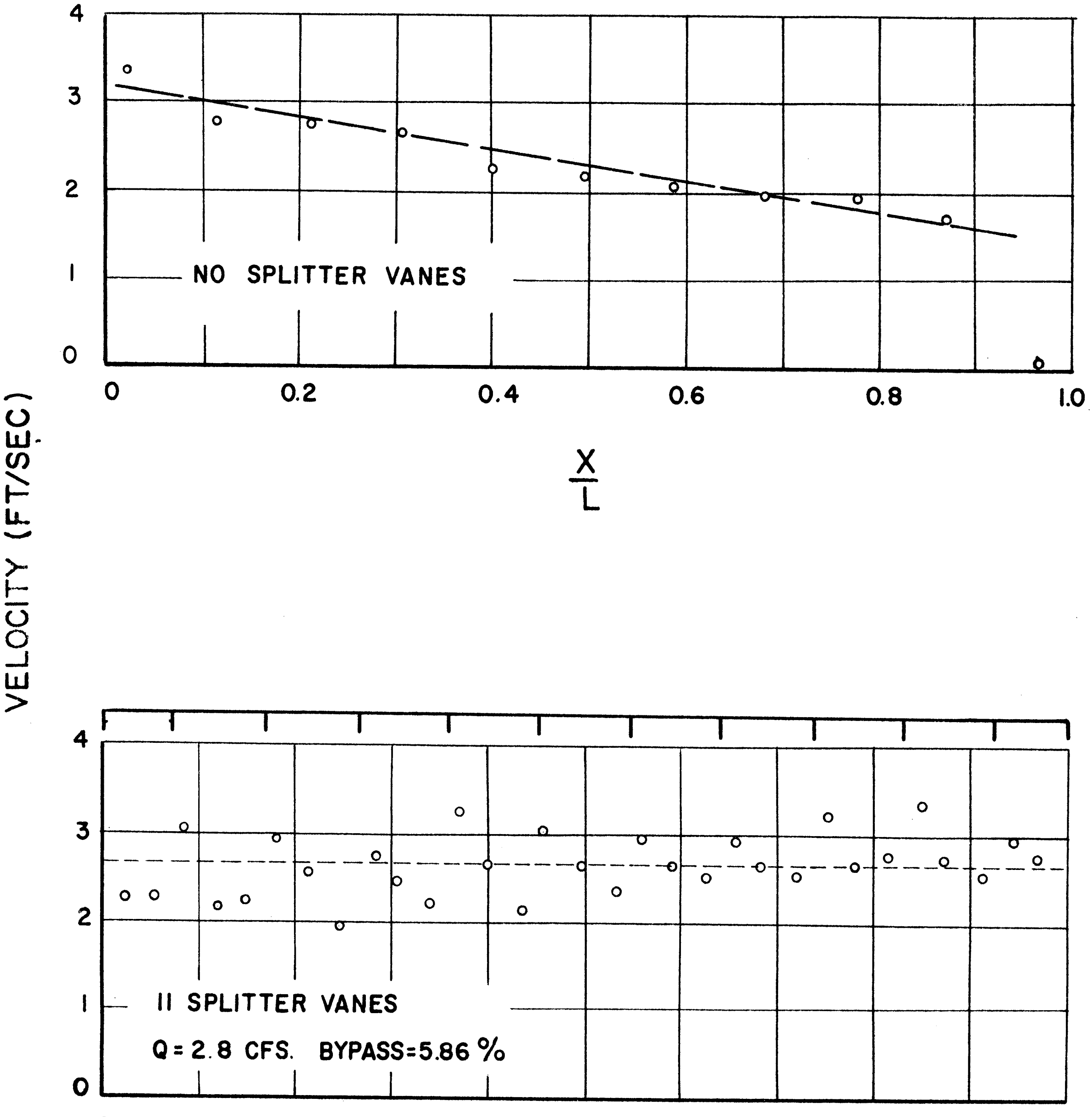


Fig. 8. Distribution of velocity along outlet of spreader for thick perforated plate (modified design with large opening).

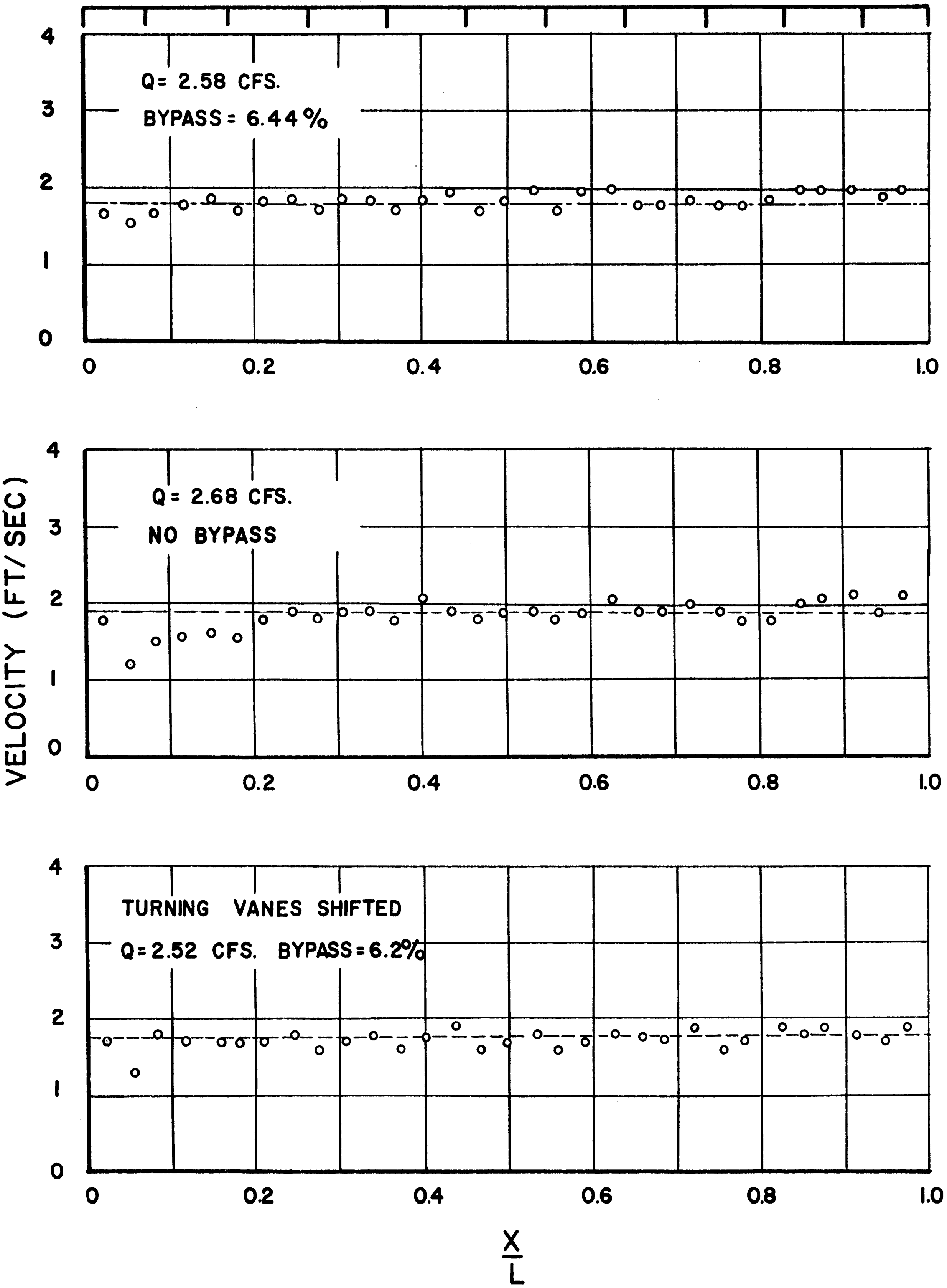


Fig. 9. Distribution of velocity along outlet of spreader for thin perforated plate (modified design with large opening).

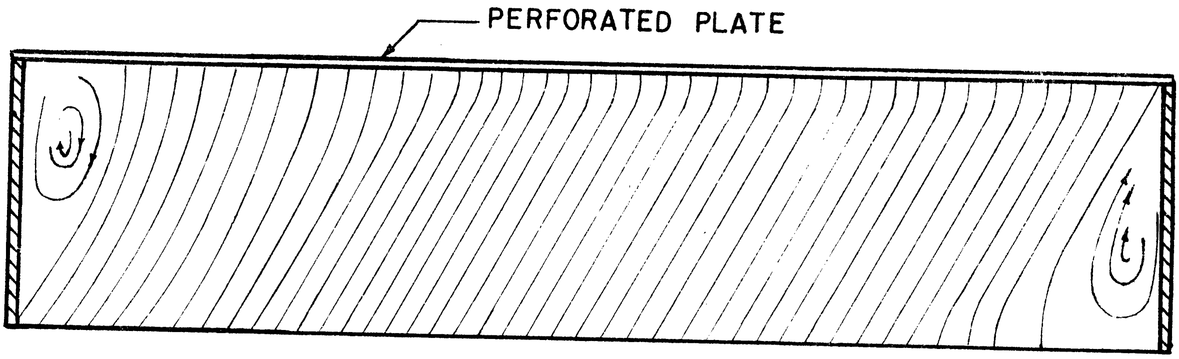


Fig. 10. Flow pattern in tapered discharge section without splitter vanes.

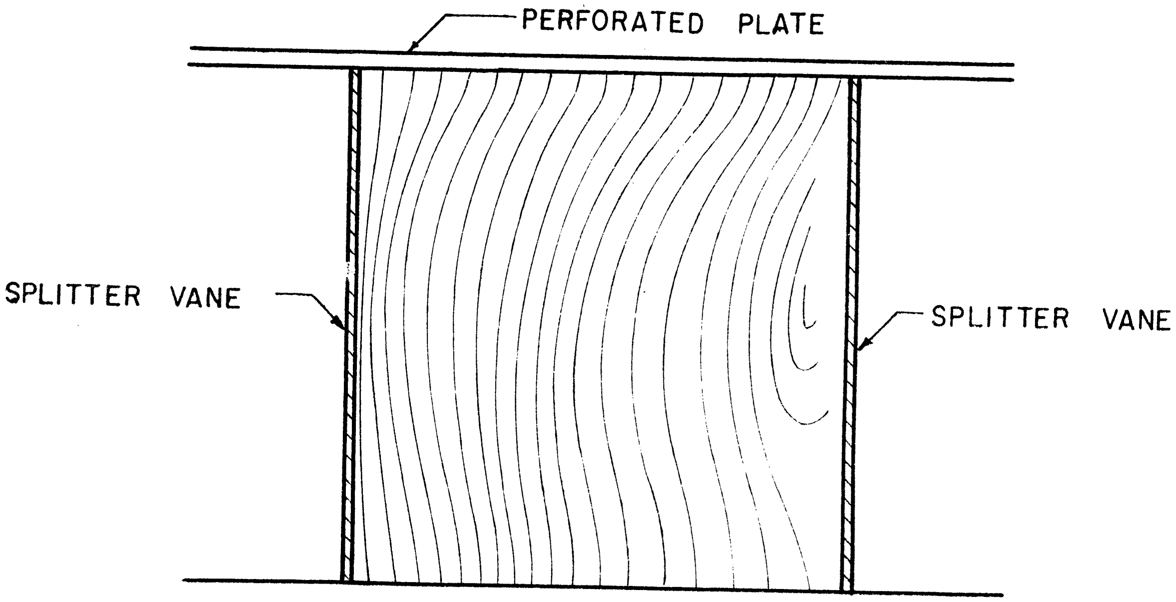


Fig. 11. Typical flow pattern in tapered discharge section with splitter vanes.

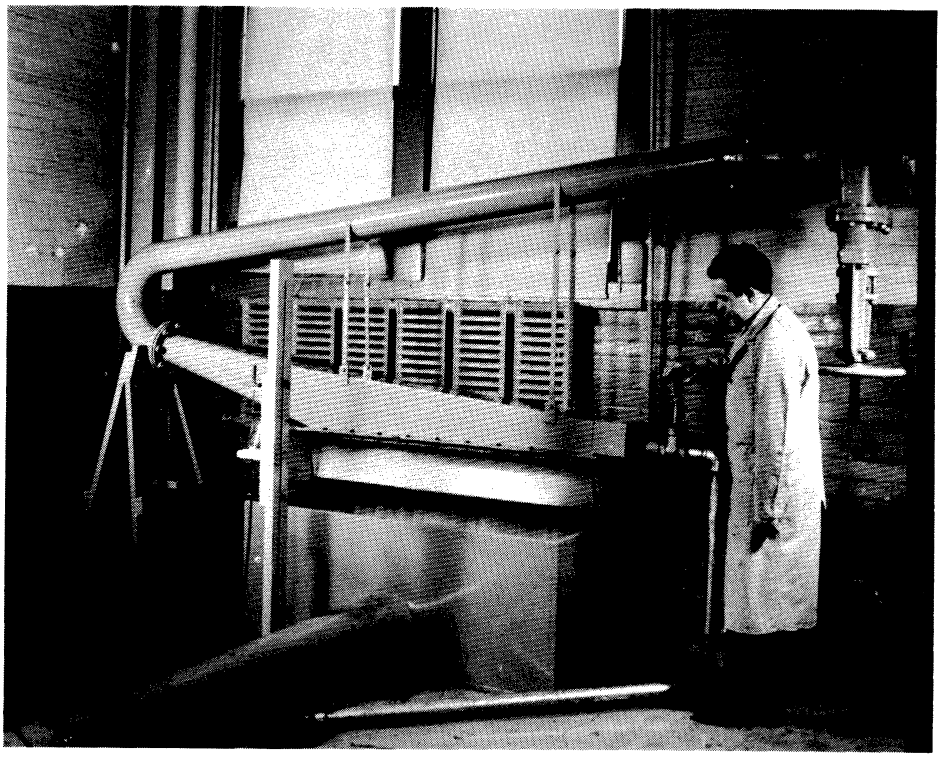


Fig. 12. Original model.

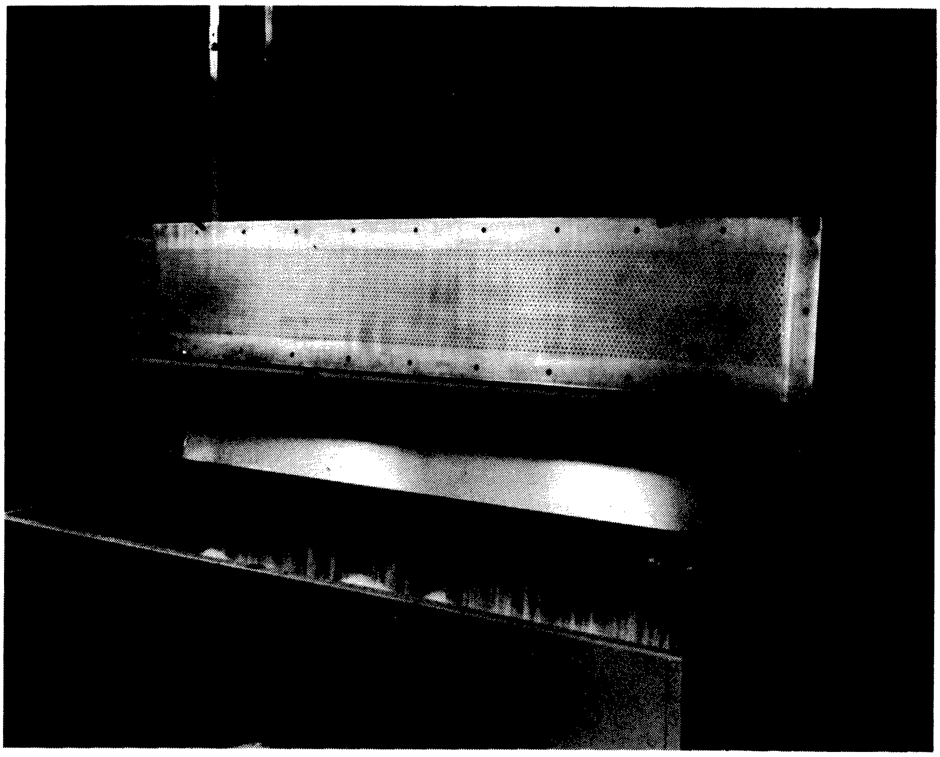


Fig. 13. Original model flowing full and perforated spreader plate.

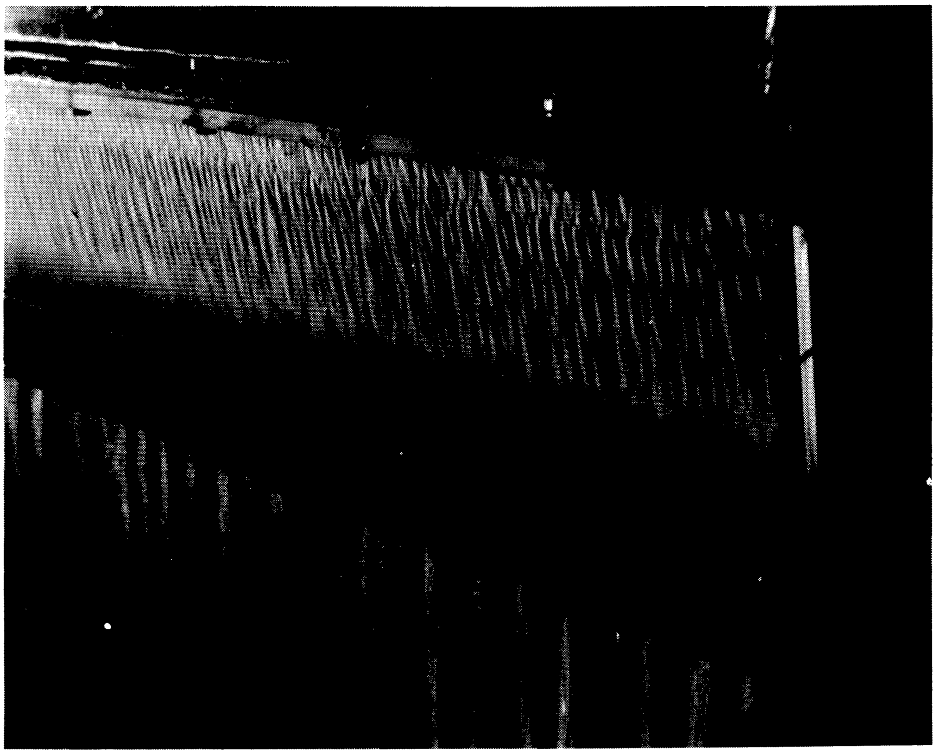


Fig. 14. Original model showing the jets from the spreader plate.

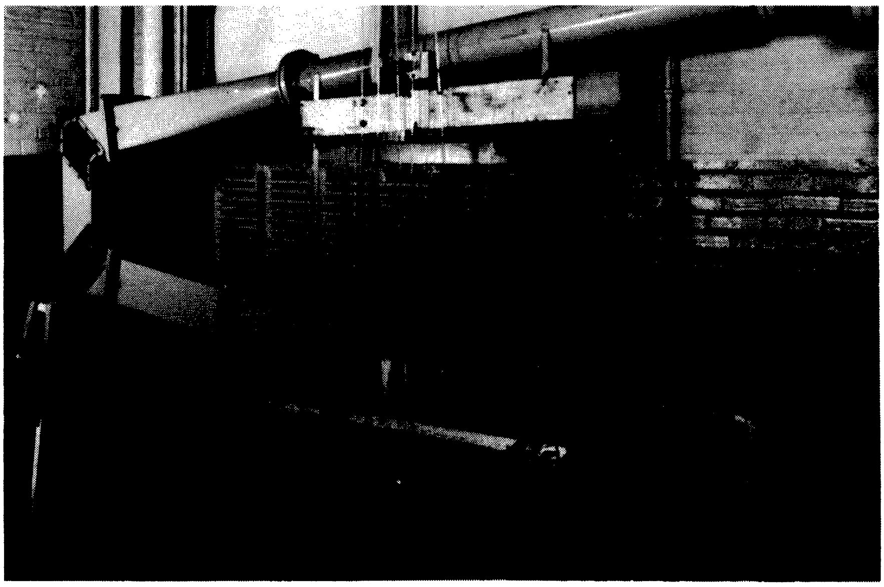


Fig. 15. Modified model.

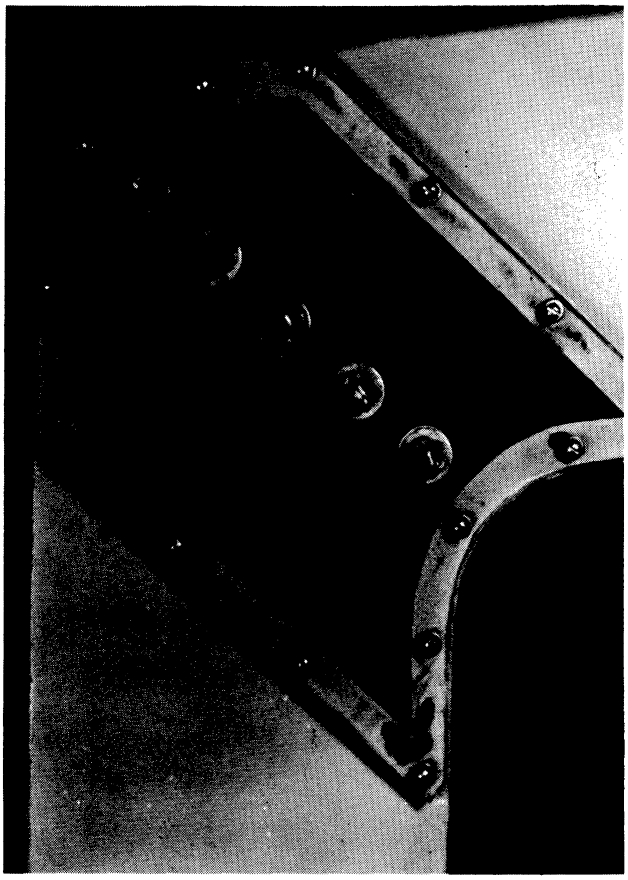


Fig. 16. Adjustable turning vanes.

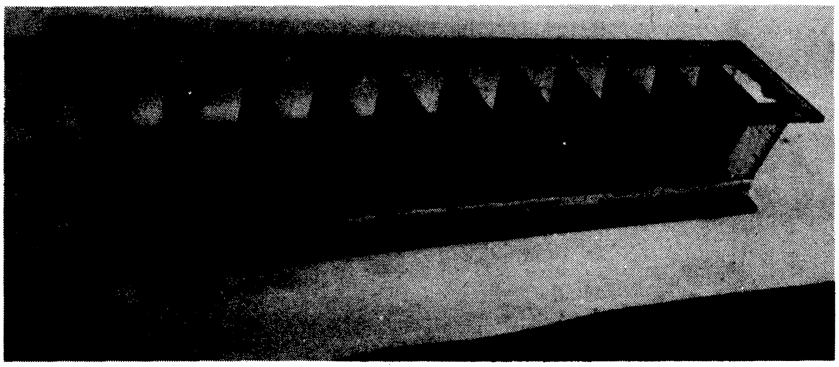


Fig. 17. Trapezoidal section with splitter vanes.

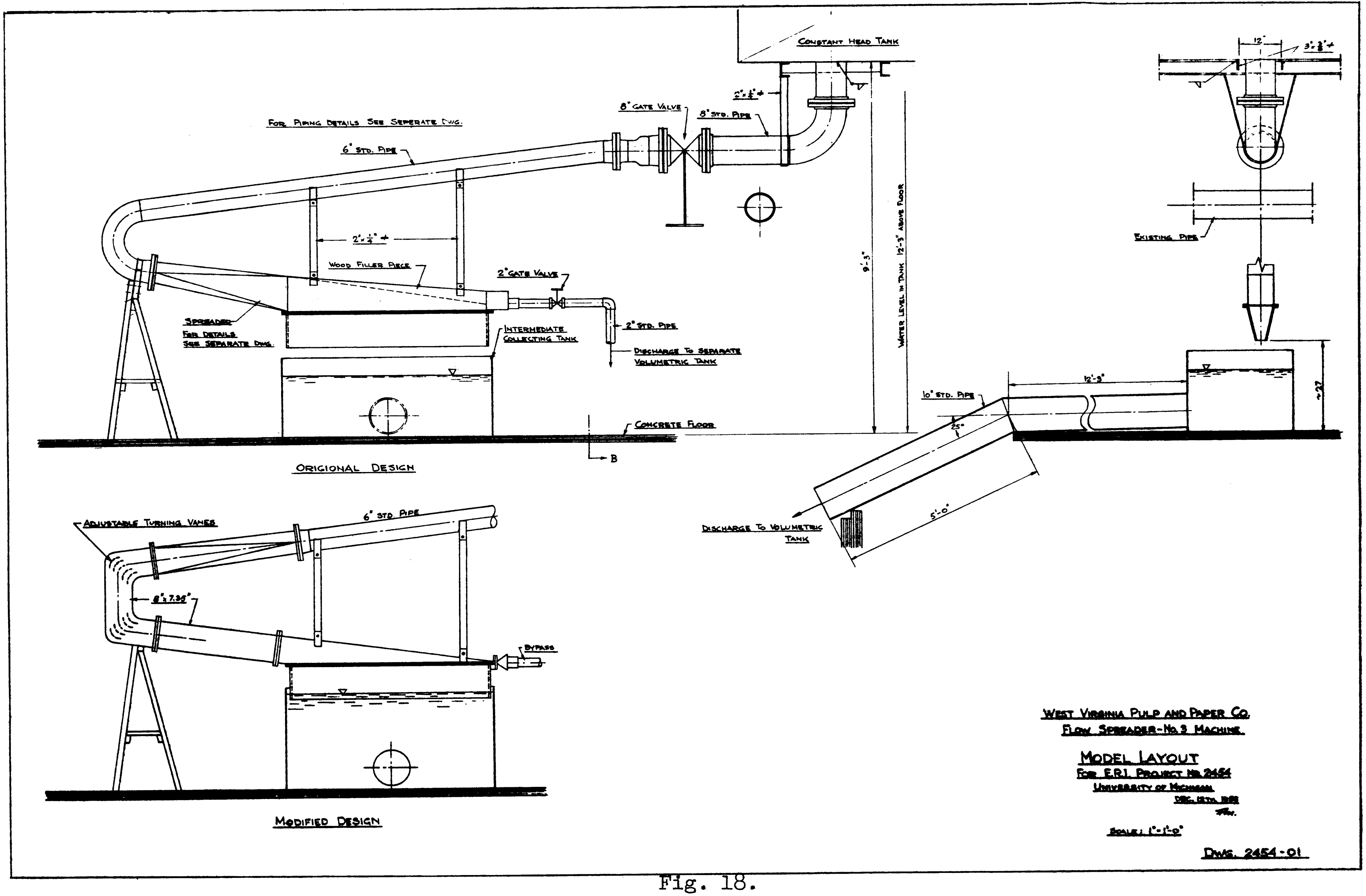

Constant Head Tank
2" x 1/4" ⌀
8" Gate Valve
8" Std. Pipe
For Piping Details See Seperate Dwg.
6" Std. Pipe
2" x 1/4" ⌀
Wood Filler Piece
2" Gate Valve
2" Std. Pipe
Discharge To Separate Volumetric Tank
Spreader
For Details See Separate Dwg.
Intermediate Collecting Tank
Concrete Floor
B
Origional Design
9'-3"
Water Level in Tank 12'-3" Above Floor
12"
3" x 3/8" ⌀
Existing Pipe
12'-3"
~27
10" Std. Pipe
25°
5'-0"
Discharge To Volumetric Tank
Adjustable Turning Vanes
6" Std Pipe
8" x 7.35"
Bypass
Modified Design
West Virginia Pulp and Paper Co.
Flow Spreader-No.3 Machine
Model Layout
For E.R.I. Project No. 2454
University of Michigan
Scale: 1"=1'-0"
Dwg. 2454-01

Fig. 18.