FEASIBILITY STUDY OF A RADIAL-FLOW ENERGY DISSIPATOR FOR CULVERT OUTLETS

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TABLE OF CONTENTS

Introduction

Erosion at the outlets of highway culverts is a common cause of damage to culverts, to the highway right-of-way, and to adjacent property. The cost of repair and maintenance due to this damage is a serious waste, which could be reduced, if better methods were available to control the erosion damage.

The cause of the erosion is understood, but to date most methods for controlling it have met with limited success. By its nature a culvert concentrates the flow of a stream into a narrower passage than the natural stream channel. For culverts on steep grades outlet velocities may range from 10 feet per second up to 30 feet per second. In order to prevent erosion at the culvert outlet these high velocities must be reduced and flow should be spread outward toward the normal width of the channel. The conventional stilling basin is not effective in increasing the width of the flow before it discharges into the natural channel. It is believed that a more effective and efficient stilling basin can be designed if a way is found to cause the flow to spread laterally before the hydraulic jump occurs. The depths would then be reduced and the structure would be less costly.

The present investigation was undertaken to explore the feasibility of developing a type of stilling basin which would be effective in causing the flow to spread rapidly as a means of achieving more efficient energy dissipation and scour control.

Previous Studies

A great deal of work has been done on the development of energy dissipators for hydraulic structures of various kinds. Some of this work dealt with the design of baffle walls or piers placed to deflect the flow and promote energy dissipation within the structure (Refs. 2,3,4,5)*. Reference 6 describes the development of transition geometry to minimize energy loss and downstream scour where flow leaves a pipe culvert and enters an unlined canal.

* References are listed by number at the end of the report.

A number of energy dissipators have been proposed for small structures, comparable to highway culverts, but they have not gained wide acceptance due to complicated construction problems and to the dangers of clogging with debris. A considerable effort has been devoted to hydraulic jump stilling basins which are commonly used on major hydraulic structures (Refs 2,4,5,7).

Other work related to this investigation is included in references 8 - 12. References 8 and 9 deal with the flow of a radial jet on a flat plate when submerged in the same fluid. It is concerned with the boundary layer effects and the turbulent mixing zone between the high velocity fluid and the overlying quiescent fluid. Since there is no free surface, the gravity effects are absent, and there are significant differences between this flow and the one proposed for the new type energy dissipator.

References 10 - 12 deal with radial free surface flow and are closely related to the anticipated flow in the new type energy dissipator.

Experimental Studies

The exploratory studies of the feasibility of the radial-flow type culvert energy dissipator could best be done by means of a hydraulic model. Variables, which were basic to the performance of a culvert energy dissipator, were selected as follows:

- y_t = the flow depth at the entrance to the energy dissipator
- y_2 = the flow depth at the outlet of the energy dissipator
- F_t = the Froude number of the flow entering the energy dissipator
- x = the longitudinal distance measured to the leading edge of the hydraulic jump
- b = the width of the culvert
- B = the width of the downstream channel

Approximate ranges for these variables based on expected field conditions were selected after consultation with personnel of the Texas Highway

* References are listed by number at the end of the report.

Department and U. S. Bureau of Public Roads.

As a result of these initial studies, it was decided that the feasibility of using the energy dissipator with a box culvert should be investigated first. A wood and fiberglass model was then built to accommodate a culvert flow 6 inches wide and 4 1/2 inches deep for a variety of entering Froude numbers and a variety of downstream channel conditions. The stilling basin portion had a maximum width of 3 feet and would accommodate flaring wing walls, with angles from twenty to ninety degrees from the centerline. Temporary walls could be installed within the basin to reduce the basin width to any desired value. The general characteristics of the model are shown in the photographs and diagrams of Figures 1, 2 and 3.

Parameters defining the geometric characteristics of the proposed stilling basin were defined as shown in Figure 3.

The model apparatus was built in the hydraulics laboratory of the Civil Engineering Department at The University of Texas at Austin, utilizing the circulating flow system and various measuring instruments, and other equipment available in the laboratory.

As a result of observing the flow in the stilling basin as originally designed, some modifications in geometry were made, which greatly improved its operation. A key factor in achieving the desired spreading of the flow was the sudden change in direction as the flow leaves the vertical curve and impinges on the horizontal apron. It was found that flow conditions were improved when the flare of the wing walls began a short distance upstream from the sudden angle change of the bottom.

<u>Results and Discussion</u>

From visual observation of the flow it was apparent that the flow was effectively spread on the apron floor with a good portion of the flow extending out to the flared wing walls. Observations, both with

θ = to 30 degrees (60 degrees total flare angle), and with θ = to 45 degrees (90 degree total flare angle) confirmed the effectiveness of the sudden change in bottom angle as a means of causing the flow to spread.

The stabilizing effect on the hydraulic jump was demonstrated by varying the tailwater y_2 over a suitable range. As anticipated, when the tailwater was high, the jump moved up toward the beginning of the flare, forming a jump of narrow width. As the tailwater was reduced the jump moved downstream in the flare and formed a progressively wider jump until the end of the flare was reached and the jump was confined between parallel walls. The stabilizing effect of the spreading flow within the flared wing walls is shown in Figure 4 by the range of tailwater which produce a stable jump. The results are presented in dimensionless form with the tailwater depth y_2 expressed as a ratio to the entering flow depth of y_t and plotted against the entering Froude number F_t for different values of the relative position of the beginning of the jump $\frac{x}{y_t}$. With the arrangement tested, it is evident that for a given Froude number the tailwater can fluctuate an amount equal to about 50% of the entering flow depth y_t as the jump shifts its position along the axis of the stilling basin.

Velocity measurements made downstream from the jump are shown in Figure 5, and indicate rapid spreading of the flow in the stilling basin. In this figure the velocity is expressed as a ratio to the mean velocity in the downstream channel. These velocities were measured near the bottom (0.03 ft.) as an indication of the potential for local scour. As the line of measurement was moved downstream the bottom velocities reduced rapidly especially in the central area. Visual and other observations indicated that the flow above the bottom was fairly evenly spread across the section.

Conclusions

The exploratory tests demonstrated the feasibility of the idea for a radial-flow stilling basin. The new type stilling basin appears to have the following advantages:

1. The flow from the culvert is spread in width, thus reducing the concentrated scour attack inherent in the narrow concentration of flow from a conventional culvert.
2. The radial-flow between the flared wing walls provides stability of the hydraulic jump over a wide range of tailwater conditions as compared with a conventional two-dimensional stilling basin.
3. There are no constrictions, baffle walls, or overhead members, which might catch debris and cause clogging.
4. The surfaces are simple, making for ease and economy of construction.

Need for Additional Investigation

Because the new type of radial-flow culvert energy dissipator has been shown to be feasible and to have certain apparent advantages over other types of energy dissipators, additional investigation is needed in order to develop methods for the design of such structures. Items that need investigation include the following:

1. The operation of basin over the complete range of important parameters
2. The effect of different types of partial sills or end sills on the operation of the basin.
3. Methods for adapting the radial-flow stilling basin for use with circular culverts.
4. The use of the radial-flow stilling basin discharging into trapezoidal channels of various configurations.

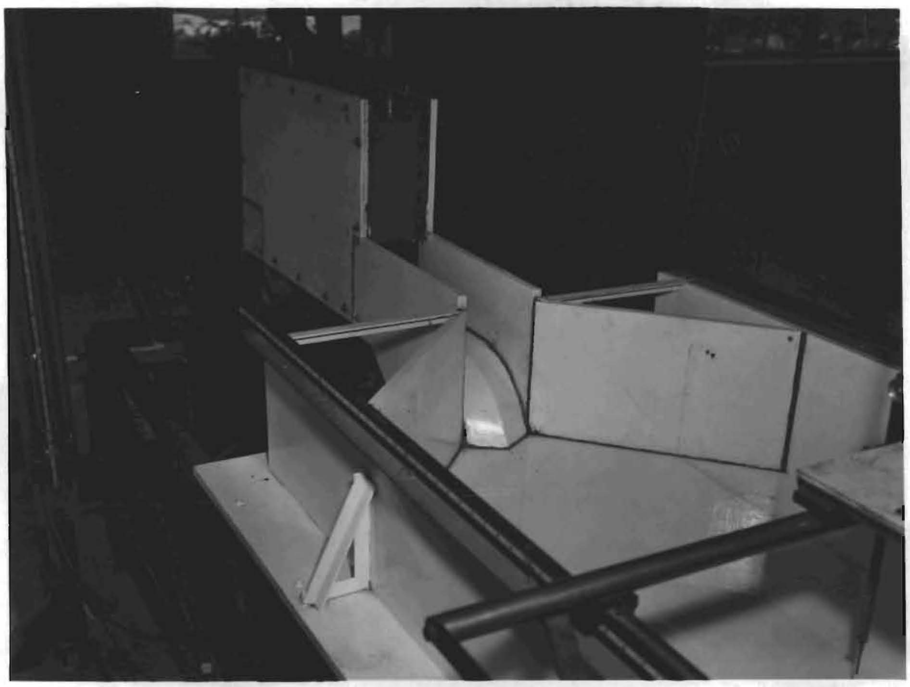

FIGURE 1 EXPERIMENTAL APPARATUS

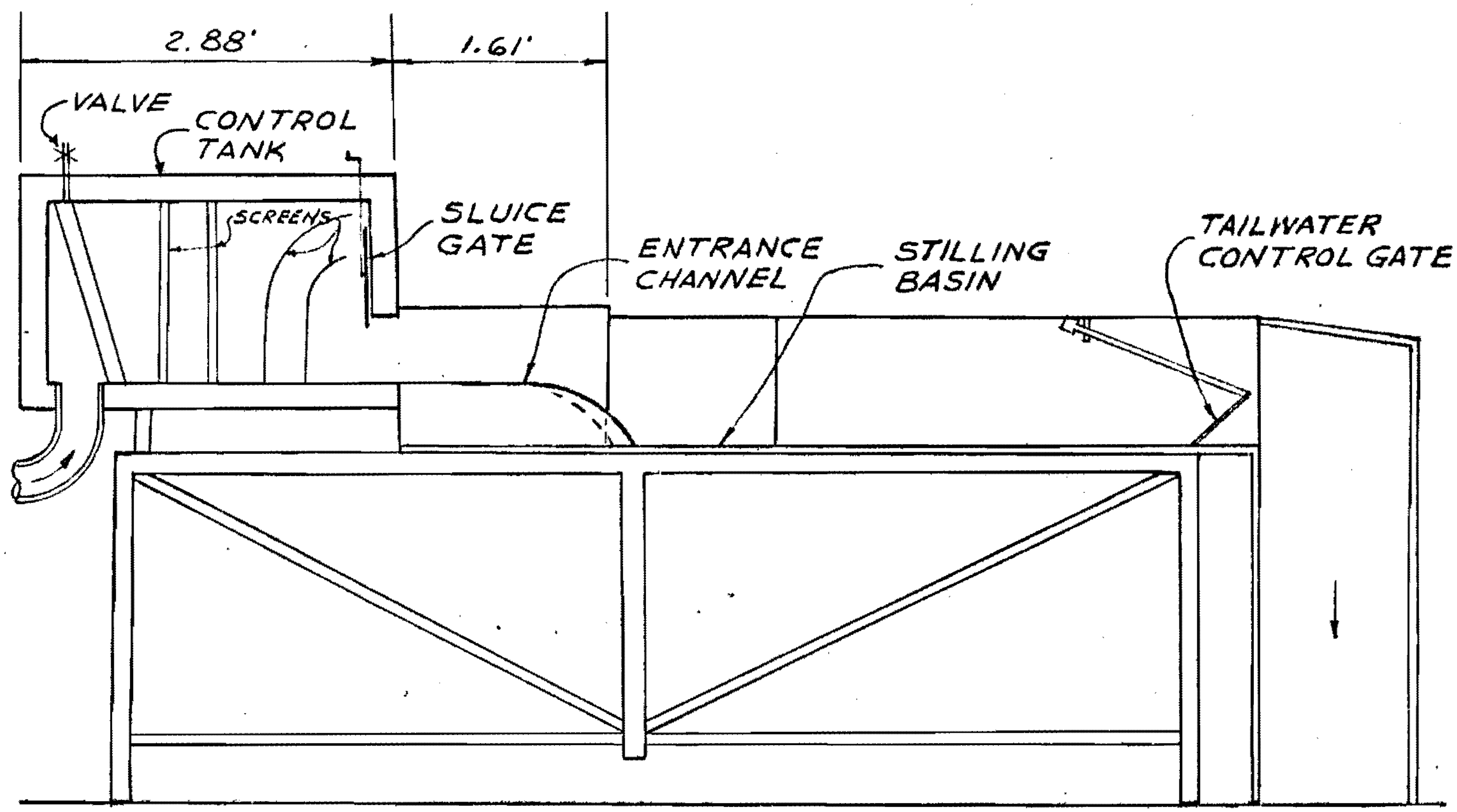

FIGURE 2 SECTIONAL DIAGRAM OF APPARATUS

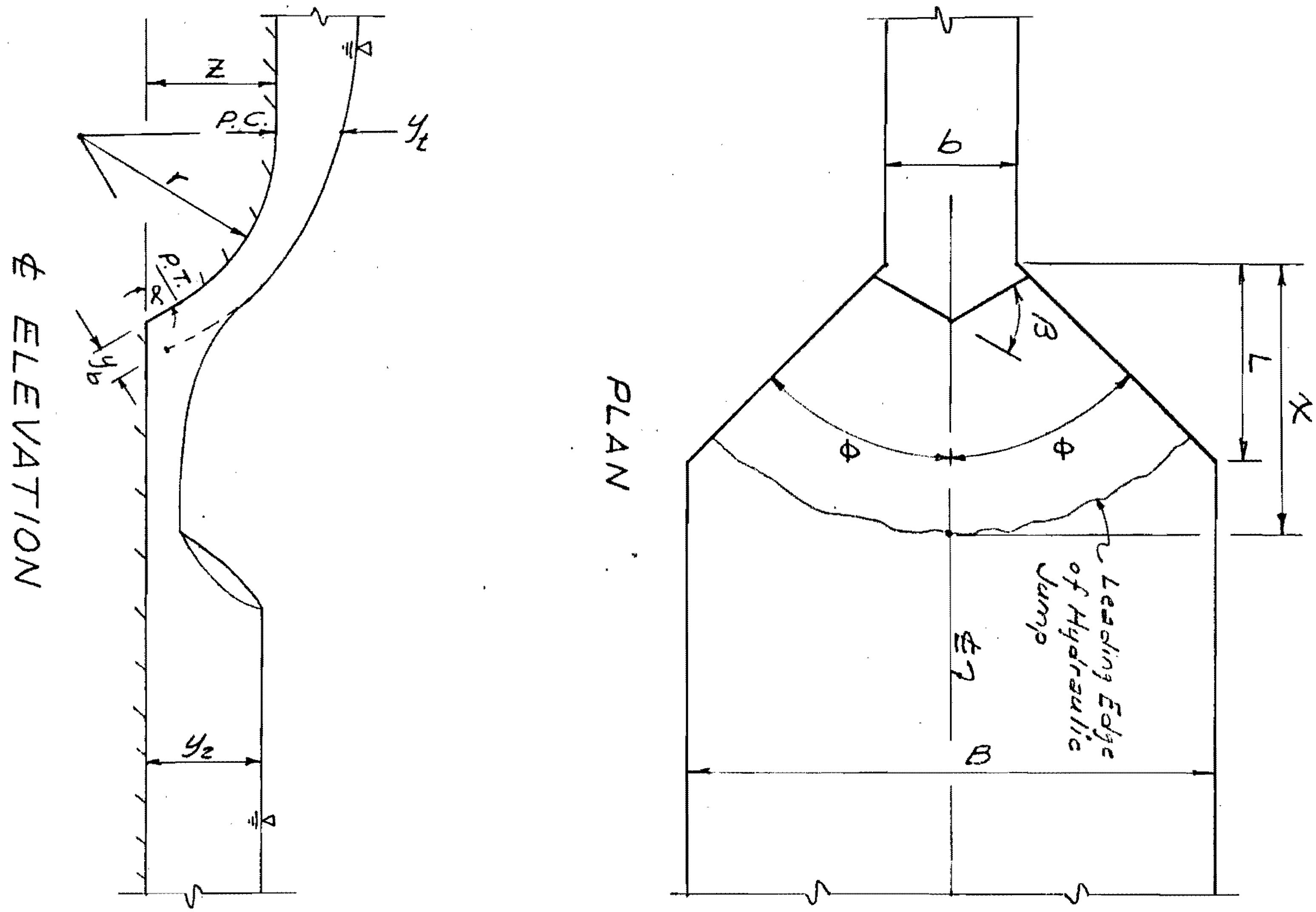

FIGURE 3 DIAGRAM OF STILLING BASIN SHOWING DEFINITION OF PARAMETERS

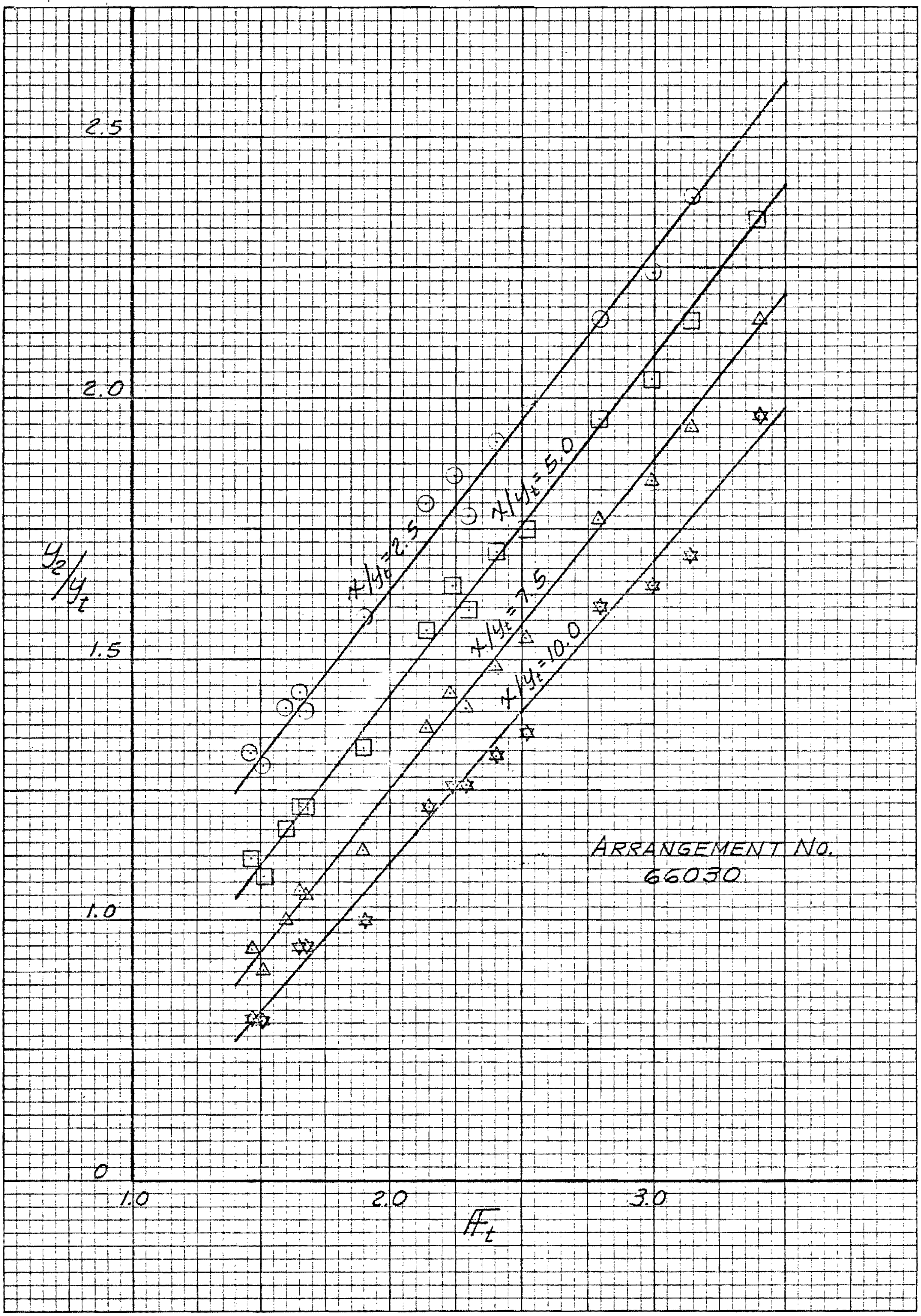

FIGURE 4 STABILITY OF HYDRAULIC JUMP IN RADIAL-FLOW STILLING BASIN

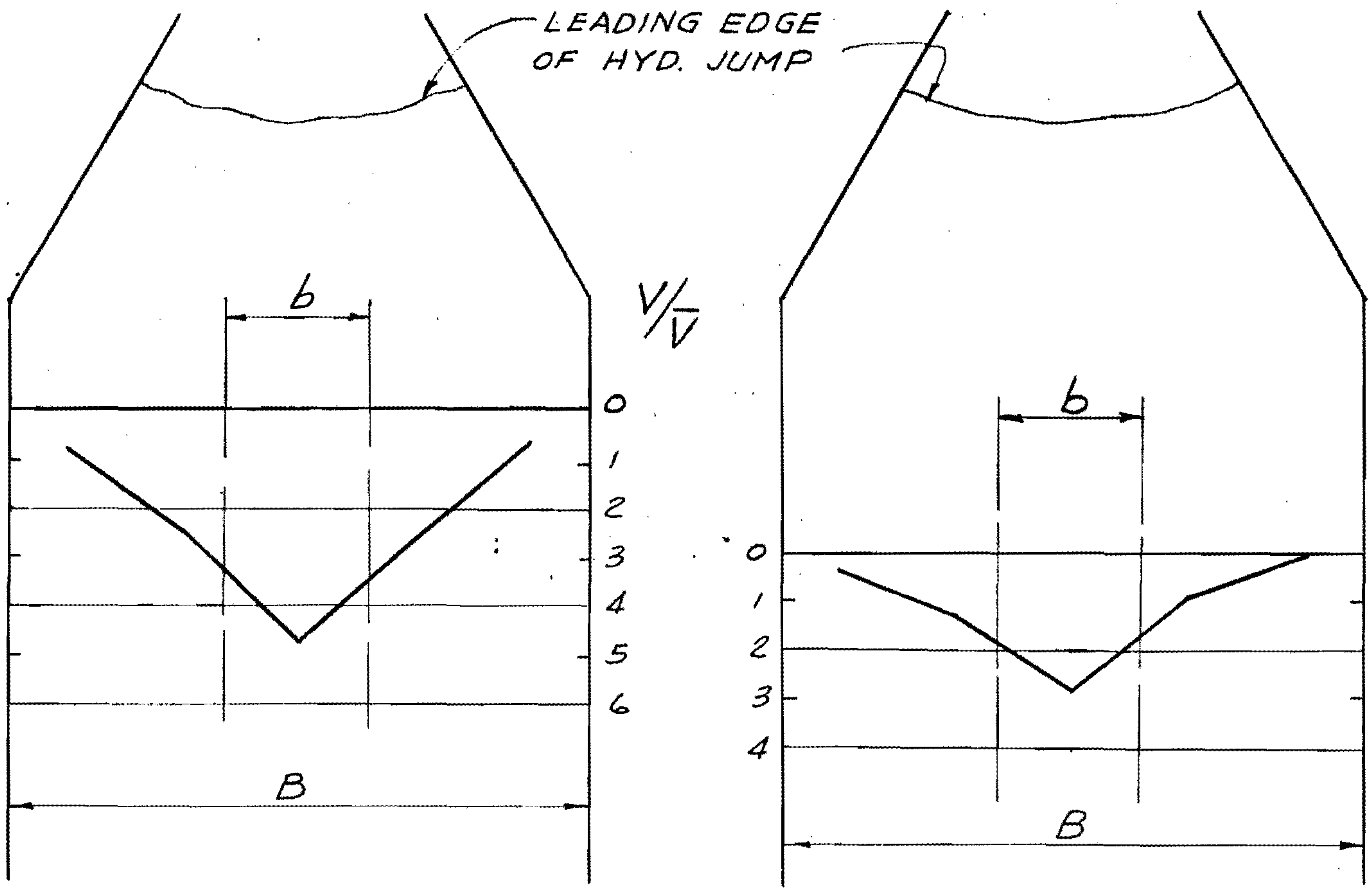

FIGURE 5 VELOCITY VARIATION ACROSS CHANNEL WIDTH

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