

March 3, 1960

To the Graduate Council:

I am submitting herewith a thesis written by Paul Yates entitled "A Hydraulic Channel Model for Research and Teaching." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

C. H. Shelton
Major Professor

We have read this thesis
and recommend its acceptance:

James T. Price
Erwin K. Boyce

Accepted for the Council:

Oslo Mantling
Dean of the Graduate School

A HYDRAULIC CHANNEL MODEL FOR
RESEARCH AND TEACHING

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A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Paul Yates
March 1960

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ACKNOWLEDGMENT

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CHAPTER I

INTRODUCTION

Value of Models as Visual Aids

In any learning endeavor, visual aids will generally facilitate a better understanding of the subject by the student. Of course, use of prototypes will generally be more satisfactory; however, in soil and water studies, prototypes are seldom available for classroom utilization. Although pictures, charts, or other figures are effective visual aids, they will rarely be as satisfactory as a model of the subject being discussed.

The proper use of models is one of the most valuable assets available to the persons interested in teaching and research or experimentation. The specific uses of models are almost unlimited. Through visual observation by the student and through the law of similitude, which states that like configurations of causes produce like configurations of results, progress in both teaching and research will advance much more rapidly when models are used. (4)

Importance of Structure in Teaching

Probably one of the more difficult subjects for the student to comprehend is that of fluid mechanics, or hydraulics, and its various aspects, such as stream flow. Agricultural engineers interested in the proper control of agricultural water should be able to develop and to apply more efficient techniques when equipped with a more thorough understanding of the various aspects of stream flow.

Julius Weisbach is quoted as saying in the preface to his "Experimental-Hydraulik,"

Only by seeing experiments performed is it possible for a beginner to grasp correctly the manifold hydraulic principles that experience has established; to keep them in mind permanently; and to form correct opinions regarding them. Absolute exactness and clearness by means of large-scale demonstrations are of the greatest value in college and university instruction to back theoretical explanation. Actual demonstrations of converting pressure head into velocity head, and vice versa, of the propagation of waves and fluid motions accompanying them, of the phenomena of flow of water in flumes, discharges over weirs and through orifices, and the like, all serve to facilitate the mathematical treatment of such problems and to impress all of it thoroughly on the mind.⁽²⁾ [sic]

Importance of Structure in Research

In the field of research it is improbable that progress will be made satisfactorily without the use of models and without adequate facilities for experimentation. "Only through experimentation can hydraulics be made a useful and serviceable science in everyday life."⁽²⁾

Much experimental and research work remains to be done in the field of agricultural water control. The tremendous amount of manpower and money being expended by such agencies as the United States Department of Agriculture Agricultural Research Service (ARS) and Soil Conservation Service (SCS) indicates the importance that authorities place upon this subject.

More research is needed in the design of effectual and practical water control structures, such as weirs, flumes, and spillways. Due to the time and expense involved in experimental work with prototypes, a simple and economical method of construction and testing of models is desirable.

Needs in Departments of Agricultural Engineering

Many agricultural engineering departments need more efficient means of presenting to the student the subject of fluid flow. Further, only limited facilities are available to execute the many phases of research and experimentation now challenging agricultural engineers interested in farm water problems.

Agricultural Research Service Model

In order to meet some of these needs, the author became interested in the construction of a hydraulic demonstration channel for use by the University of Tennessee Department of Agricultural Engineering. Definite interest began when, as a member of a graduate class in soil and water control, he visited the ARS Research Station near Coshocton, Ohio, in October, 1958. Here he observed a similar channel, which is used in basic research and in special training schools to teach newly employed SCS technicians the principles of fluid flow and to demonstrate features of models of water control devices.⁽¹³⁾ A short demonstration by Dr. L. L. Harrold, project supervisor at the station, convinced the author that this was an invaluable teaching and research tool for anyone interested not only in agricultural water control problems but also in many phases of teaching fluid mechanics, in design, or in research and in experimentation with hydraulic models.

Cost of Structures

Upon returning from this inspection trip, Professor Curtis H. Shelton, the instructor of the class, corresponded with Dr. Harrold

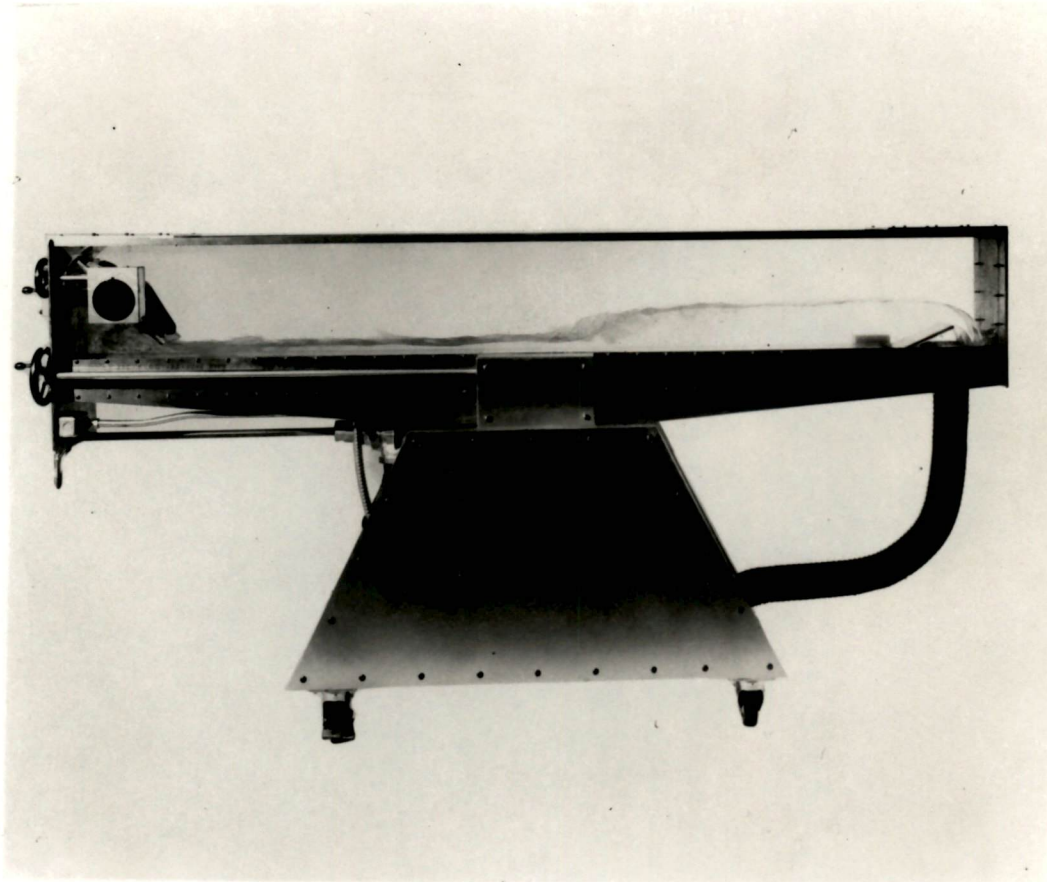


Figure 1. ARS model showing hydraulic jump.

regarding the possibility of purchasing such a demonstration channel. Subsequent correspondence led to a price quotation of eighteen hundred dollars, f.o.b. Wayzata, Minnesota.⁽⁸⁾ As this cost was prohibitive considering the budget of the department, a decision was made to construct a channel in the department shops. It was estimated by the author that this channel could be constructed at approximately one-third to one-half the quoted price, excluding labor.

CHAPTER II

OBJECTIVES

Purpose of Project

The purpose of this project was to design and to construct a portable hydraulic demonstration channel that could be used in the classroom for teaching purposes and in the laboratory for research work.

In this design and construction it was necessary to incorporate simplicity of design and operation and to consider economy a major factor. It was the desire of the author and his advisors to incorporate features, as far as practicable, that could be designed and constructed in the department shops. The principal reason for this was to keep the cost to the department at a low figure. If this objective could be accomplished, it was believed that other departments or agencies having need for such a model, but having limited budgets, would welcome plans for construction and operation.

Desirable Features

It was desirable to incorporate a number of features into the design of this unit:

1. a channel of sufficient capacity to give a reasonable simulation of stream flow;
2. provisions for both positive and negative slopes;
3. a method of controlling velocity of water flowing through the channel;

4. a method of controlling quantity of water flowing through the channel;
5. a tailgate of adjustable height;
6. a rapid and easy method of installing and removing structure models;
7. adequate support strength to insure steady flow conditions without channel vibrations;
8. a relatively inexpensive structure which could be constructed by other groups on a limited budget; and
9. simple construction methods which could be accomplished in shops of interested schools or agencies.

Each of these features, with its respective problems and solutions, is discussed more in detail in Chapter V, which discusses the functional requirements.

CHAPTER III

REVIEW OF LITERATURE

A. DEFINITION OF A MODEL

A model may be defined as a device or a system so related to a physical system, called the prototype, that observations on the model may be used to predict accurately the performance of the physical system in the desired respect.⁽¹¹⁾

Models are ordinarily used in studies to obtain information that will aid in the design of the prototype. Although a "cut-and-try" method of design would be excessively costly in the full-scale system, this method is relatively inexpensive in the construction of models.

Limitations of Models

It must be realized, however, that model studies do not provide easy answers to every question. One must understand the basic theory of the phenomenon that he is studying before he can interpret the results of a model test. The adage "one test is worth a thousand opinions" is true only if one realizes these truths.⁽⁷⁾

B. HISTORY OF MODEL DEVELOPMENT

Although the extreme importance of scale models in hydraulic engineering design, as well as in other fields, is generally acknowledged and accepted, little literature exists on this subject except in "the

form of papers scattered through the journals of the learned societies and the pages of the technical press."⁽¹⁾ Because these papers are readily available to few persons interested in model studies, the need for further investigation and presentation of results in this field is evident.

First Recorded Study

The first recorded study of hydraulics was evidently that of two Italians, Leonardo da Vinci in the sixteenth century and Guglielmini in the seventeenth century. However, the first fundamental treatise on hydraulics was formulated by M. Dubuat in his "Principes d'Hydraulique et de Pyrodynamique, une Nouvelle Edition, Paris, 1816." Dubuat attempted, and is credited with success, to bring into accord his own theoretical ideas and the results of his own carefully executed experiments. Without getting lost in abstract theories, he seemed to be able, in a masterly way, to make excellent use of his theories in guiding his experiments. Possibly most important, he understood how to assemble the results of his experiments into a comprehensive form from which he was able to derive rules and laws of permanent value.⁽²⁾

Dubuat, in the preface to his "Principes d'Hydrauliques," justified his work and explained his reasoning in words which are accepted even today.

We always reason correctly when we apply to a subject only such ideas as are inherent in the nature of the thing; on the other hand, we commit all sorts of errors whenever, prejudiced, we try to draw conclusions before having reasoned, to reason before having acquired knowledge, or try to know before having investigated.⁽²⁾

Darcy-Weisbach Resistance Equation

Although much of Dubuat's work has been outmoded by subsequent research, his experiments and ideas relative to the resistance of ships in channels have been of fundamental significance. The German, Julius Weisbach, in the middle of the nineteenth century engaged in similar comprehensive experimentation, one result of which was the important Darcy-Weisbach resistance equation:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} .$$

This equation was also formulated independently about the same time by the Frenchman Darcy. (2)(12)

Darcy, working with another Frenchman, Bazin, carried on both small and large scale experiments especially concerned with the motion of water in streams. They constructed a wooden flume for use as a model of a river in which to conduct their experiments. (2)

Work by Fargue

The first investigation of a hydraulics problem arising from actual practice was conducted by another Frenchman, Fargue, about 1875. The city of Bordeaux was confronted with the problem of improving the channel of the river Garonne. Controversy between opposing factions as to advisability of dredging or systematic regulation was settled as a result of his work. Building a model of the portion of the river in question and conducting experiments for a period of two years led to the knowledge that dredging could be depended upon to give satisfaction only if done in connection with regulating works. (2)

Work by Reynolds

About 1885 Professor Osborne Reynolds continued this work in England when he built models of the Mersey estuary only one to two meters in length. In proving that characteristics of the real estuary could be reproduced satisfactorily in the models, Reynolds was the first to introduce the time element into such experiments. Reynolds is quoted by Langhaar:

Experimenting with models seems to afford a ready means of investigating and determining beforehand the effects of any proposed estuary or harbor works; a means, after what I have seen, I should feel it madness to neglect before entering upon any costly undertaking.(7)

First Permanent River Hydraulics Laboratory

Further work was carried on by M. L. F. Vernon-Harcourt in England and Mengin-Lecreulx, a French engineer. Finally, in 1898, the first permanent river hydraulics laboratory was established by Engels at the Technical University of Dresden, where he undertook experimenting with models on the nature and behavior of the flow of water in natural water courses.

Early Progress in America

Although quite extensive hydraulic research and model studies had been undertaken in Europe, very little progress had been made in America prior to 1900. Despite the fact that American rivers present some of the most important hydraulic problems found anywhere in the world, Freeman reports that even as late as 1929 not one river-flow laboratory comparable to those in Germany was available in America.

This fact seemed strange because the most ambitious research program on river hydraulics ever attempted anywhere in the world was begun by two young United States Army engineers. Their work, reported in the "Researches on the Physics and Hydraulics of the Mississippi by Captain Humphreys and Lieutenant Abbott," was incomplete because the War Between the States began.

Freeman concluded that their work fell short largely because they had no

. . . laboratory in which they could work out the problems of the large river by means of models, and in which they could control and vary the conditions affecting flow, one by one, and in which they could develop a better current meter.(3)

New England School of Engineers

Possibly the first precise large scale hydraulic-laboratory experimentation was begun, about 1840, by what was called the New England School at Lowell, Massachusetts. This work was carried on by five engineers in succession: Charles S. Storrow, Uriah Boyden, James B. Francis, Joseph P. Davis, and Hiram F. Mills.

These engineers worked in such specialties as water-power development on the Merrimac River at Lowell, relations of the measured mean velocity to the center-surface velocity as shown by carefully timed surface floats, discharge coefficients, weir discharges, and such devices as turbines, orifices, and flumes.

Because of their extensive use of models over a wide range of dimensions, Freeman credits this group with a major contribution toward establishing the doctrine of hydraulic similitude. Because such

refinement of method characterized its use of models and its observations, the New England School of engineers is further acknowledged never to have been excelled in its degree of precision in hydraulic experimentation.⁽³⁾

Contributions by United States Department of Agriculture

The United States Department of Agriculture (USDA) entered the field of hydraulic models about the first of this century. Its first publication, "The Flow of Water in Irrigation Channels," by Fred C. Scobey, was published in May, 1915. The Chézy and Kutter formulas were used in arranging new data, and measurements were made of slope and discharge in a wide range of existing irrigation ditches and flumes in the West and Southwest. The values of C and n in the Chézy and Kutter formulas were determined for two hundred sixty different channels, nearly all of artificial construction and in practical use. Although these experiments were in the field, they were called laboratory experiments because of the methods and instruments used, the skill of the observer, and the wide variety of specimens used. Freeman cites this work as the most valuable of its kind performed before 1929, the time of his writing.⁽³⁾

Further work was conducted by Scobey and other USDA engineers, including C. E. Ramser, D. L. Yarnall, and S. H. Woodward. Today, practically all engineering schools are conducting some phase of hydraulics or model experiments or both. Many of these are working jointly with the USDA or some other Federal agency. A notable example is the St. Anthony Falls Hydraulic Laboratory of the University of

Minnesota in Minneapolis, where extensive research and testing has taken place in agricultural hydraulic problems, such as weir and spillway design and construction. (5)

Credit also goes to this laboratory for the design and construction of the hydraulic demonstration channel seen by the author at the ARS, Coshocton, Ohio, station. As no patent rights were involved, a set of working plans of this model were made available to the author. (10)(9)

C. LAWS GOVERNING MODELS

Whenever the laws governing the action in the prototype are known, the laws governing the relationship of model to prototype are derived from these known laws. Should these laws be unknown or indefinitely known, models can be used only qualitatively.

Dimensional Groups Used

Principles of dynamic similarity are generally used in correlating the operation of, and results obtained from, models to prototypes by use of model laws. The most commonly used relationships are expressed in the form of dimensionless groups which, by their numerical value, characterize the type of flow under consideration. Derivations of model laws are based on the assumption that for equal values of the dimensional characteristics the corresponding flow patterns in prototype and model are similar. Experimental results have verified these assumptions satisfactorily.

In hydraulic experimentation, three dimensionless groups are most

commonly used: the Froude number ($F = \frac{V^2}{Lg}$), the Reynolds number ($R = \frac{VL\rho}{\mu}$), and the Weber number ($W = \frac{V^2 L}{\sigma}$). These are derived, respectively, from a consideration of the forces of gravity, viscosity, and surface tension, in conjunction with the resisting force of inertia. (6)

In the above paragraph, the following terms apply to the symbols used: (6)

V = a characteristic velocity of the system

L = a characteristic linear dimension

g = acceleration of gravity

ρ = fluid density

μ = fluid viscosity

σ = fluid surface tension.

Froude's Law

Froude's law indicates the similarity of gravity and inertial forces in the model and prototype. When Froude's number in the model is the same as that in the prototype, the ratio of gravity forces to inertial forces is the same, and the paths of flow are similar. This law assumes that neither viscosity nor surface tension has any appreciable influence on the phenomena under investigation.

Reynolds' Number

Reynolds' number states the condition under which the ratios of viscous forces to inertial forces are the same. If Reynolds' numbers in model and prototype are equal, flow is similar in both when viscosity

and inertia are the predominant forces. Reynolds' law assumes that neither gravity nor surface tension appreciably affects the flow.

Weber's Number

Weber's number expresses equality of the ratios of surface tension to inertial forces in model and prototype, assuming that gravity and viscosity forces are negligible. Flow patterns are similar in model and prototype for equal Weber's numbers when surface tension is the controlling factor.

CHAPTER IV

FACILITIES AVAILABLE

It was pointed out in Chapter II that a primary objective of this project was to develop a structure which could be easily duplicated by other schools or agencies.

Construction Facilities Required

Relatively few facilities, all of which were available in the University of Tennessee Department of Agricultural Engineering shops, were required to construct this project. Tools and equipment for such processes as cutting, drilling, and welding metal would probably be found in shops of any organization desiring to undertake construction.

There are a few jobs which might be accomplished more efficiently by contract with a machine shop. These include such procedures as dadoing the plexiglass stream walls, constructing the screw mechanism for channel slope adjustment, and machining parts of the headgate and tailgate control mechanisms.

Operation Facilities Required

Operation also requires few facilities. Only a water source, an electrical power source, and small floor space are needed. As the structure is mounted on casters for mobility, the space required for classroom or research work can be easily vacated when the channel is not in use.

CHAPTER V

DESIGN OF MODEL

A. FUNCTIONAL REQUIREMENTS

Methods of obtaining complete control of the variable factors affecting water flow had to be obtained in order to make proper use of this channel in teaching. Likewise, in research, each factor had to be controlled completely and independently of all others. Therefore, these conditions necessitated provisions for establishing the desired slope, both positive and negative, the quantity of water flowing through the channel, the velocity of water flowing, and a tailgate of adjustable height to serve as a water retention wall or dam.

A number of satisfactory devices for controlling each of the above factors could have been incorporated into the model. Possibly other methods would have been equal to or better than those chosen by the author. As was mentioned earlier, however, simplicity and economy were to be maintained at all times. Plans of the ARS model were available as a guide but could not be followed closely because of the desire for economy and because of the decision to make a larger channel. For example, it was more economical to construct a rectangular tank with exposed motor and pump than a trapezoidal tank with enclosed motor and pump.

In the following sections the author presents a brief discussion of procedures for constructing the various parts of the project. Photographs of stages of construction appear at the end of the chapter.

Channel Capacity

With a width of six inches and depth of twelve inches, the ARS channel was deemed rather small for satisfactory construction and use of models within the channel. However, this width possibly would be satisfactory if the channel were to be used for observation or teaching of fluid flow only.

A decision was reached to make this channel twelve inches wide, eighteen inches deep, and eight feet long. This wider channel should provide for better observation of flow past model structures after the passageway is constricted with structural materials and after allowances are made for effects of boundary conditions.

Tank

The capacity of the channel, including the intake and discharge hoses, would be approximately one hundred fifteen gallons when full. To allow a safe margin, the tank was designed for a capacity of approximately one hundred fifty gallons: forty-eight inches long, twenty-four inches high, and thirty inches wide. A simple construction plan, as shown in the drawings (see Appendix), using angle iron frame with sheet metal tank was considered the most practical method. Drawings of major components and a schedule of parts appear in the Appendix.

Base Frame

The tank frame was lengthened to provide a mounting frame for the pump and motor. Also attached to the tank frame were three screw jack devices primarily to be used for leveling. However, they also

take some of the weight from the casters and serve as brakes to prevent rolling. These jacks were constructed with one-inch bolts, head down, and nuts welded to the frame. Another nut was then welded to the upper end of each bolt, and a cross arm was welded to each nut for turning.

Pump and Motor

Calculations showed that a pump with a capacity of three hundred gallons per minute was required. This was exactly three times the pump capacity used on the ARS model, which had a channel capacity of only one-third that of this structure. A pump of this capacity necessitated a five horsepower motor, according to the pump manufacturer's specifications.

A Gardner-Denver Type B centrifugal pump with capacity of three hundred gallons per minute at forty feet head was purchased. Although various other pumps would have been satisfactory, this one was chosen for two main reasons: a satisfactory electric motor was already on hand to work with this type of pump, and this motor would not work with any of the built-together units, which consequently could not be considered.

Channel Support and Slope Adjustment

Numerous methods of mounting the channel above the tank were considered. Not only was necessary strength for supporting the channel required, but also means of adjusting channel slope had to be incorporated into this support.

First consideration was given to a single pivot support with a worm gear arrangement similar to that used in the ARS structure. This idea was eliminated, however, because it would have required the purchase of more costly parts, such as worm gear and sector, than some other methods. Sometime after deciding against a single support, the author received a letter from Fred W. Blaisdell, Project Supervisor at the St. Anthony Falls Laboratory, stating that the laboratory had realized the necessity of two supports to insure a steadier channel.⁽¹⁰⁾

Some type of scissors jack was next considered as a means of controlling channel slope. This was soon agreed upon by the author and his advisor as probably the most simple and economical method. Proper location of this jack then had to be determined. Had the jack been located at one end of the channel with the other end as a pivot, the elevation range would have been over thirty-three inches, which was considered quite unreasonable.

Another possibility consisted of an arrangement of two jacks, one at each end of the channel with a pivot support in the center. This was quickly abandoned because of the difficulty involved in arranging the two to work together.

Finally the decision was made to use the method shown in the drawings, a pivot point twenty-four inches from one end and a jack installed twenty-four inches from the other end. This required a maximum elevation difference of nearly seventeen inches to provide a slope range from plus ten degrees to minus ten degrees. An investigation at local automotive supply houses revealed no scissors jacks with an adequate elevation range; therefore, one was designed and built as shown.

Channel Design

Design of the channel was not complicated. Consideration was first given to use of a T-beam placed on its side to support not only the main channel floor but also both main channel and sub-channel walls. Angle iron would then be used to support the sub-channel floor and to attach the floor to its wall. However, it was later concluded that the method finally chosen required less metal and less welding.

Channel ends of sheet steel were attached to the channel by use of angle irons welded in a position vertical to each corner of the channel.

Emphasis must be placed on the importance of the extreme care required in the welding during the fabrication of the channel. Unless proper precautions had been taken, the heat of welding would have caused excessive warping of parts, creating quite undesirable construction conditions.

Headgate and Tailgate

Headgate and tailgate design rather closely followed those of the ARS model with the headgate pivoting on its center axis and the tailgate pivoting at the bottom. Aluminum gates and brass shafts were used to reduce the possibility of rust.

Slope Indicator

A slope indicator consisting of an ordinary carpenter's level with attached vernier was considered. However, this idea was eliminated as the calibration would have been rather difficult. The method chosen,

the use of two transparent tubes clamped vertically to the channel sides, was simple and inexpensive. These two tubes were then connected by a flexible rubber hose through which the colored fluid could pass. (Water with any coloring added to permit clearer visibility is recommended as suitable fluid.) Graduations as shown in the drawings indicated the channel slope, ranging from positive ten degrees to negative ten degrees.

Model Installation

Serious consideration was given to duplicating the method used in the ARS channel--use of screws into the channel bottom. However, due to the desire to eliminate totally any conditions which might affect flow patterns undesirably, a design requiring no screw holes or screw heads was preferred.

It was further desired to place a plexiglass or a similar smooth material on the channel floor to give smoother flow. Therefore, the decision was reached to have two pieces of one-fourth inch thick plexiglass installed. One end of each piece was placed even with a channel end and the pieces extended to within one-eighth inch of the middle of the channel, leaving a space one-fourth inch wide and one-fourth inch deep, into which the lower extremity of any model could be inserted. It was assumed that one-fourth inch plexiglass would be satisfactory for model construction. When models are not in use, a square strip of plexiglass may be inserted into this space to give a continuous surface.

Additional support of the models is provided by the use of brackets clamped to the upper channel side rails. These are quickly and easily

installed or removed by use of set screws. These brackets, along with the upper channel frame, will also facilitate the use of various devices such as flow meters by providing a ready method of attaching the devices at any point along the channel.

Cost of Structure

Materials. Most of the materials for this structure were purchased from business concerns in Knoxville, Tennessee, at prices shown in the Appendix. However, some items were on hand in the University of Tennessee Department of Agricultural Engineering. On all such items, price quotations were obtained from dealers and used in determining total cost of the structure. The cost of welding rods, electricity, and a few miscellaneous small pieces of metal is not included in these calculations.

Total cost of materials as shown in the Appendix amounted to \$721.22. With a liberal allowance for the items mentioned above, total cost would be approximately \$750.00.

Labor. No accurate record of total time spent on this project was kept. However, such a record would be rather valueless as it would not be a true account of time required. Much time was spent in trial and error efforts no longer necessary. A builder following directly the plans given in the Appendix of this thesis can now prepare and fabricate parts easily.

Assuming the builder to be reasonably proficient in metal work and the use of plexiglass, the author estimates a time requirement of

approximately two hundred hours to reproduce the structure. More time must necessarily be allowed if shop conditions are inferior.

An estimation of time required to construct the various parts of the structure is as follows:

Base frame assembly	35 hours
Tank and tank frame	20 hours
Mounting pump, motor, and intake	5 hours
Jack mechanism	15 hours
Pivot mechanism	5 hours
Channel frame, walls, floors, and ends	35 hours
Prepare and install plexiglass	25 hours
Headgate	25 hours
Tailgate	25 hours
Slope indicator	5 hours
Gate valve, pipes, and hose	<u>5 hours</u>
Total	200 hours

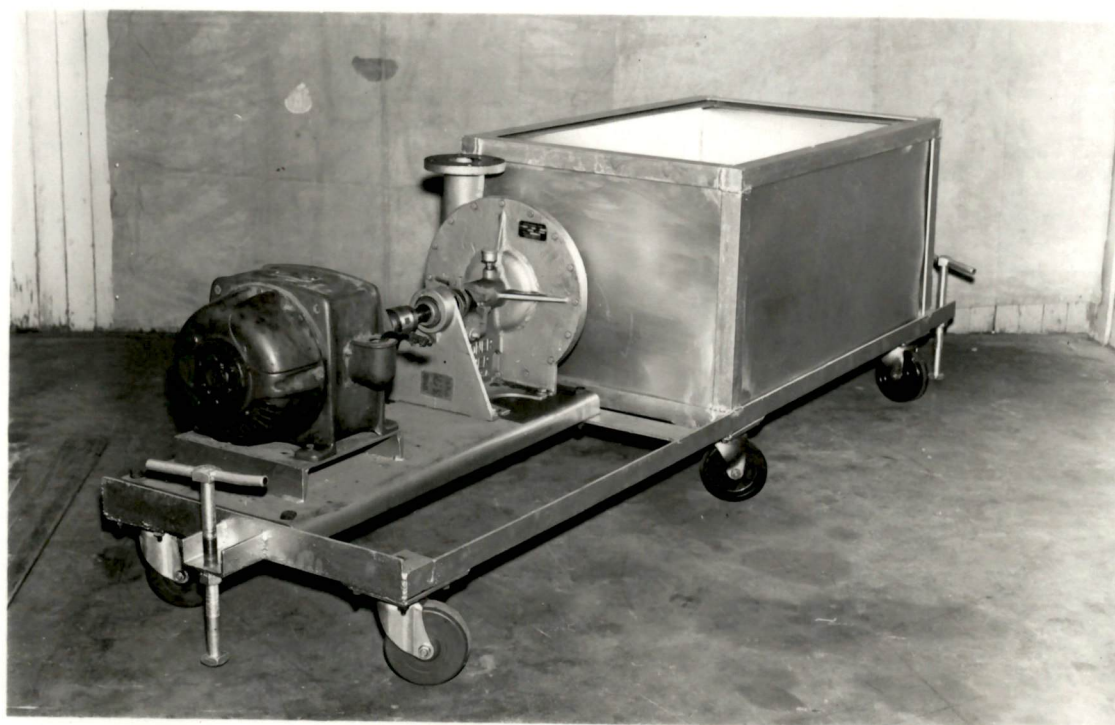


Figure 2. Base assembly with tank, pump, and motor. Front side.

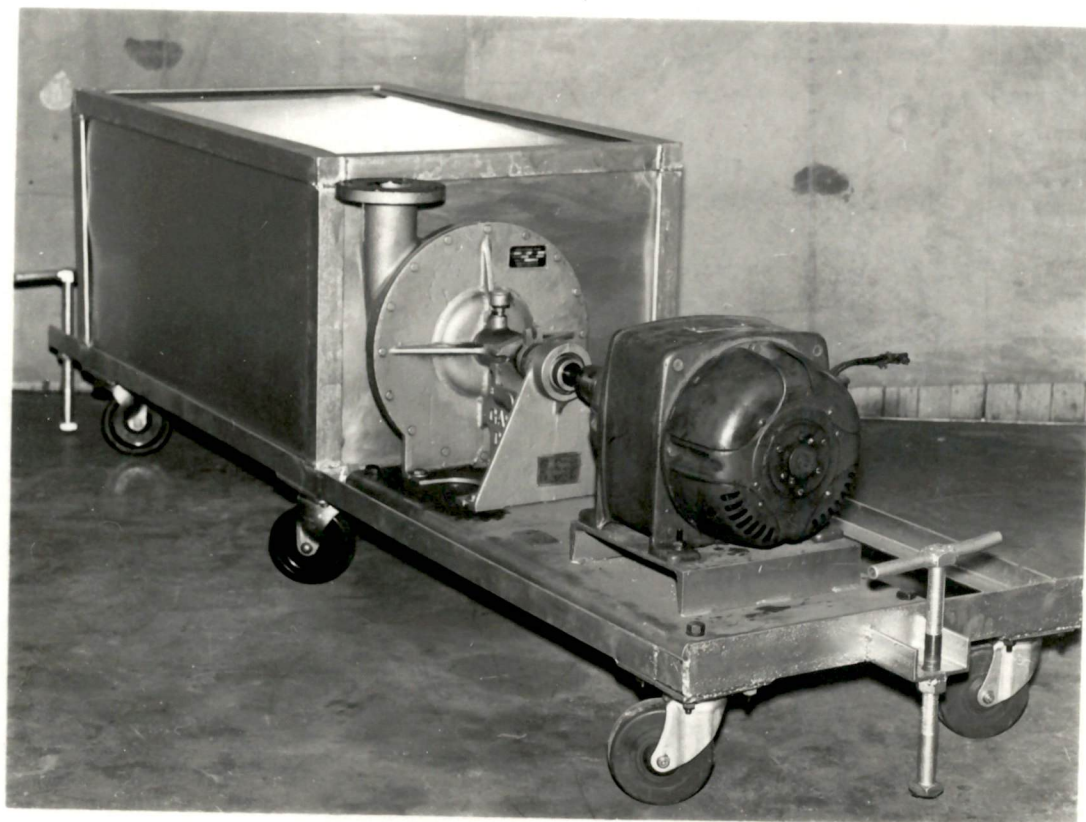


Figure 3. Base assembly with tank, pump, and motor. Back side.

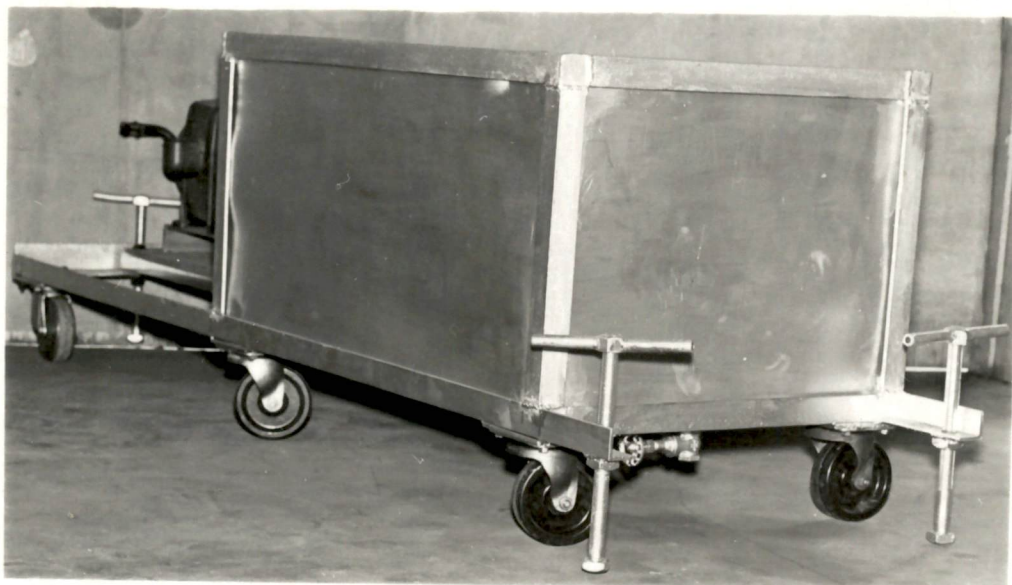


Figure 4. Base and tank with leveling jacks. End view.

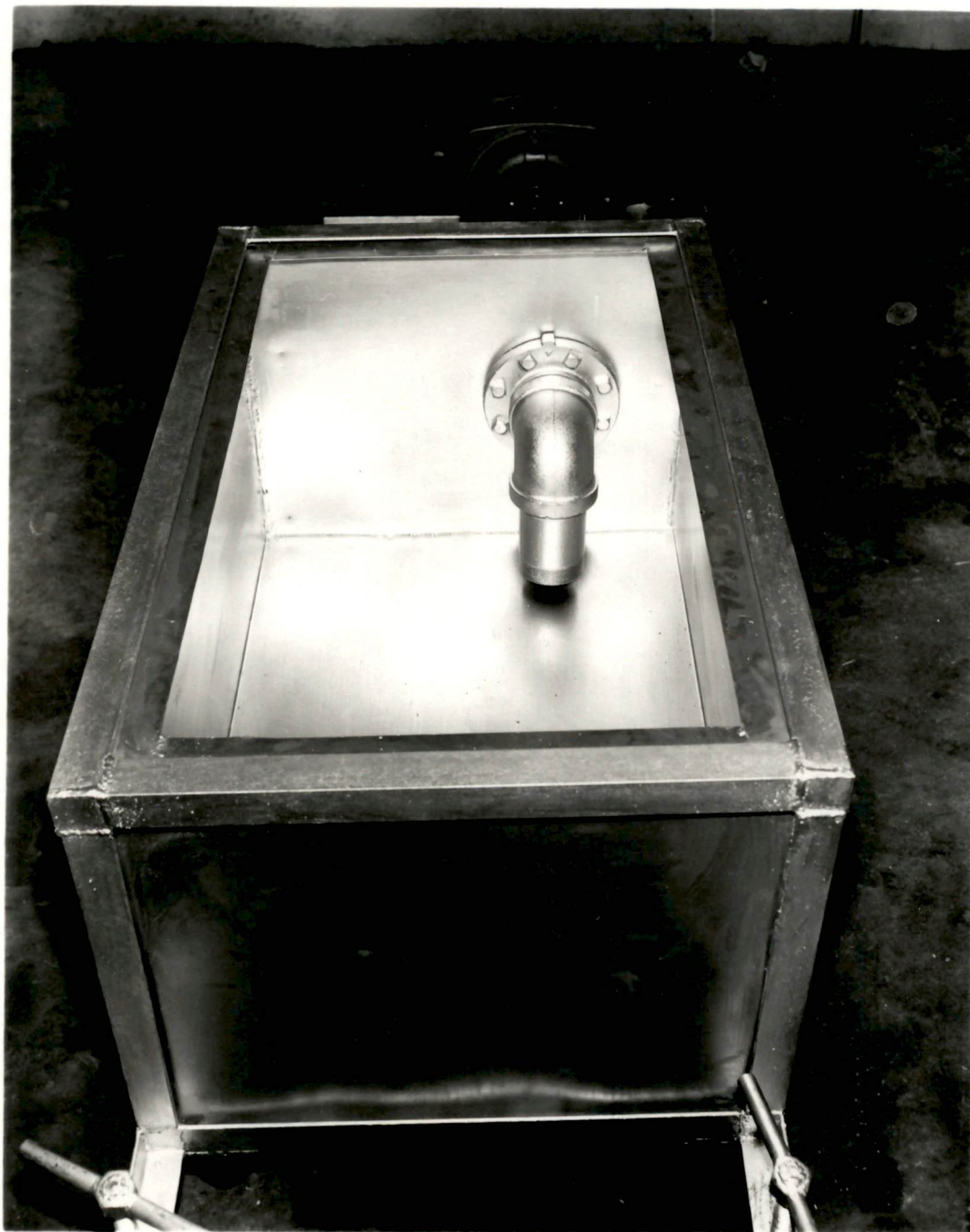


Figure 5. Top view of tank showing pump inlet.

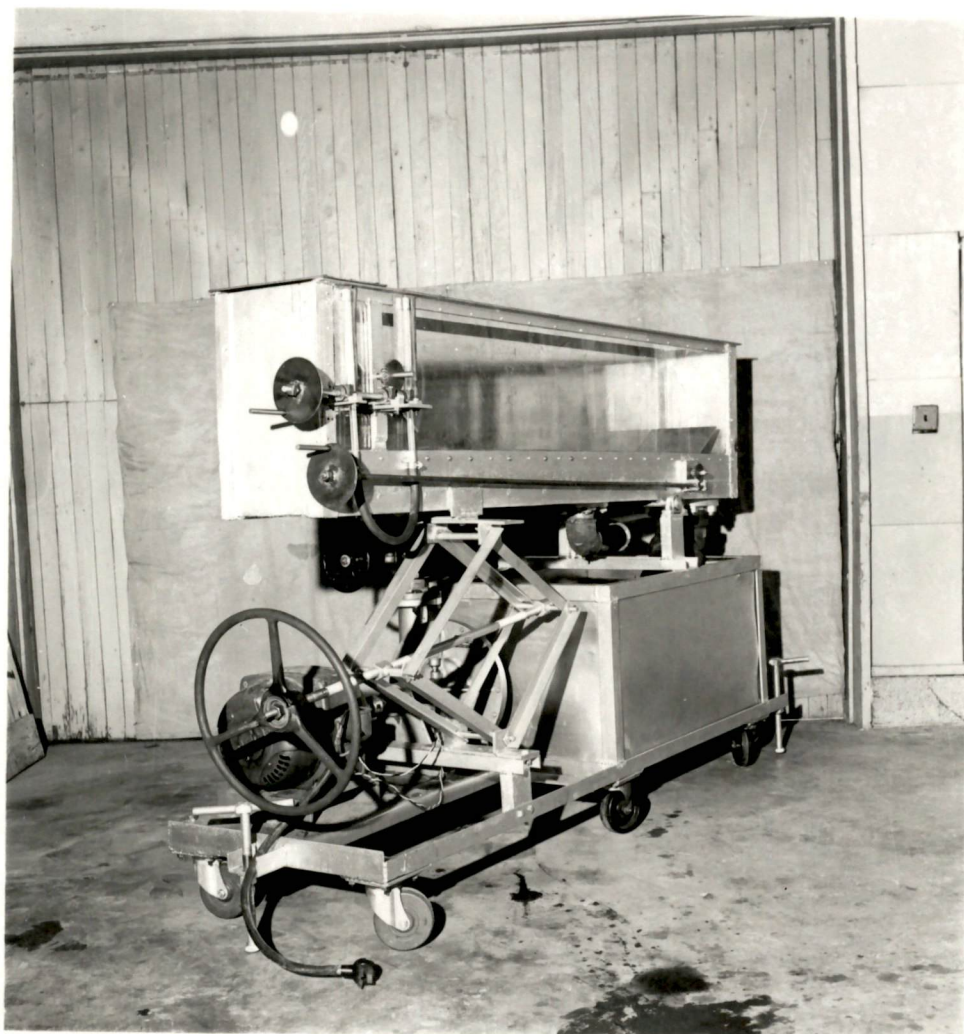


Figure 6. Completed model. Front side.



Figure 7. Completed model. Back side.

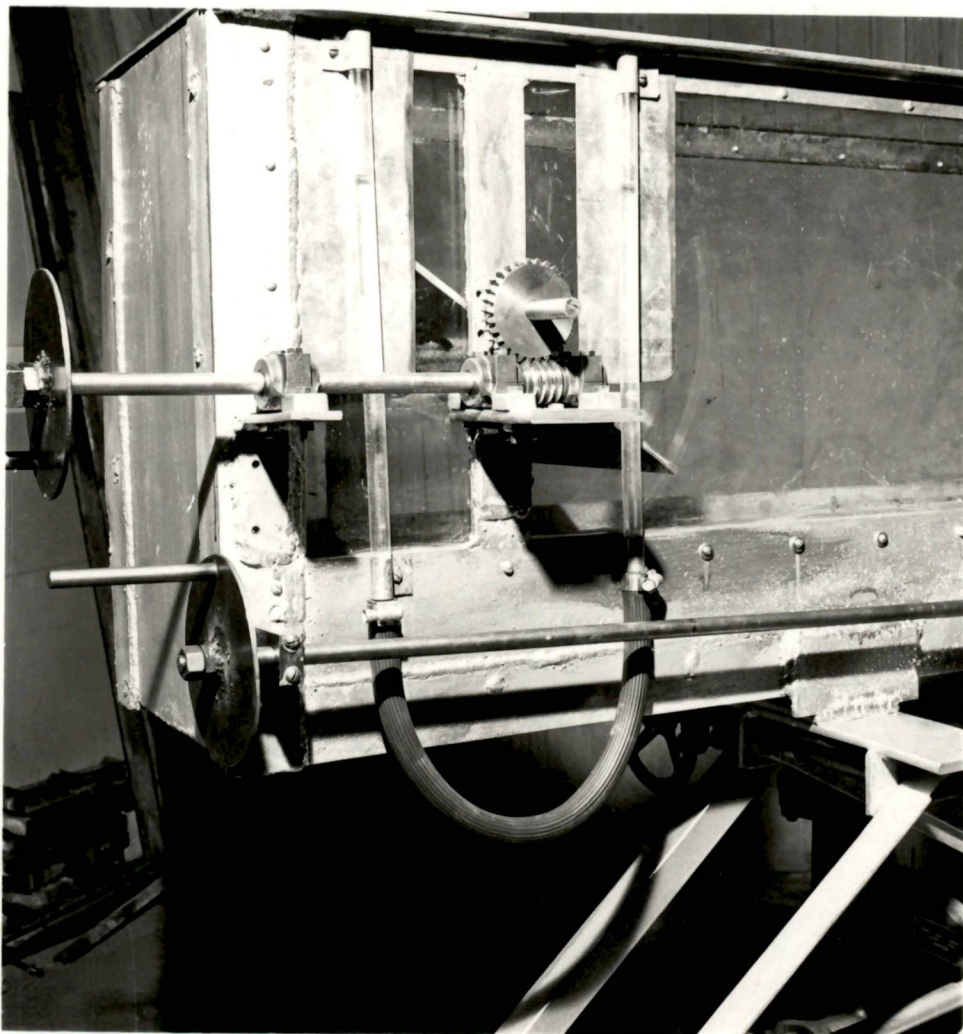


Figure 8. End view showing headgate control mechanism and slope indicator tubes.



Figure 9. Front side showing tailgate and tailgate control gears and channel pivot.

CHAPTER VI

CALIBRATION

Functional Requirements

Any calibration of flow should provide means of measuring both quantity of flow and velocity of flow. Each of these measurements should be easily made and should be made completely independently of each other as desired.

These requirements have not yet been completely met. (See Chapter IX on recommendations for further work.) Some type of flow meter--venturi, orifice, or elbow--could be installed to be used as a satisfactory measuring device. Use of such devices as weirs placed in the channel for measurement necessitates the addition of stilling well and hook gages to obtain reasonable accuracy.

Quantity of Flow

The only calibration performed on this channel involved the use of a three-inch National Meter Company flow meter installed between the gate valve and the channel entry while the channel was in a level position. About five readings were taken at each of four different gate valve openings: one-fourth open, one-half open, three-fourths open, and completely open. Measurements were taken in cubic feet per minute. Average values of these readings have been converted to gallons per minute in the following table.

TABLE I

FLOW RATES WITH VARYING VALVE OPENINGS

Gate Valve Opening	Cubic Feet Per Minute	Gallons Per Minute
1/4	21.0	157.0
1/2	29.2	218.4
3/4	30.1	225.1
Open	30.6	228.9

Velocity of Flow

No calibration on velocity of flow was performed by the author. It is recommended that this be done at various headgate openings when a satisfactory flow meter has been provided.

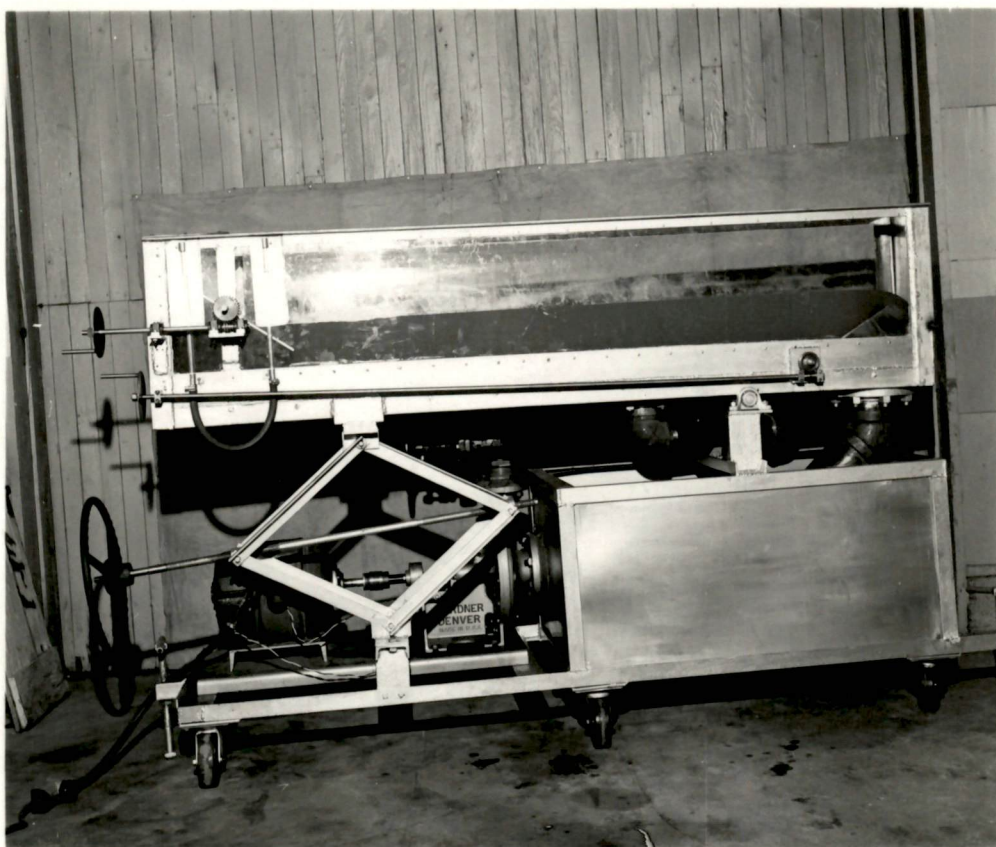


Figure 10. Channel in normal operation.

CHAPTER VII

APPLICATIONS TO TEACHING AND RESEARCH

Introduction

It would be virtually impossible to list all the potential uses of this demonstration channel. Problems will continue to arise which, after a preliminary analysis, could be solved when submitted to model tests. Also, the author realizes that the channel, having certain limitations, cannot be an answer to every problem confronted. Therefore, it must be emphasized that this discussion is only a presentation of some possible uses.

In this chapter, a listing of some possible uses of the model in both teaching and research is first presented. Following this, the author presents three examples: one a teaching demonstration, one a laboratory problem, and one a research project. Each of these could be used as presented or could be modified readily as desired.

Outline of Possible Uses in Teaching and Research

A. Teaching*

I. Hydrostatics

1. Unit pressure
2. Variation of pressure intensity with respect to elevation or depth

*As well as benefitting the professional agricultural engineering student, many of these demonstrations could be valuable in teaching service courses for the general agriculture student with no technical knowledge of fluid mechanics.

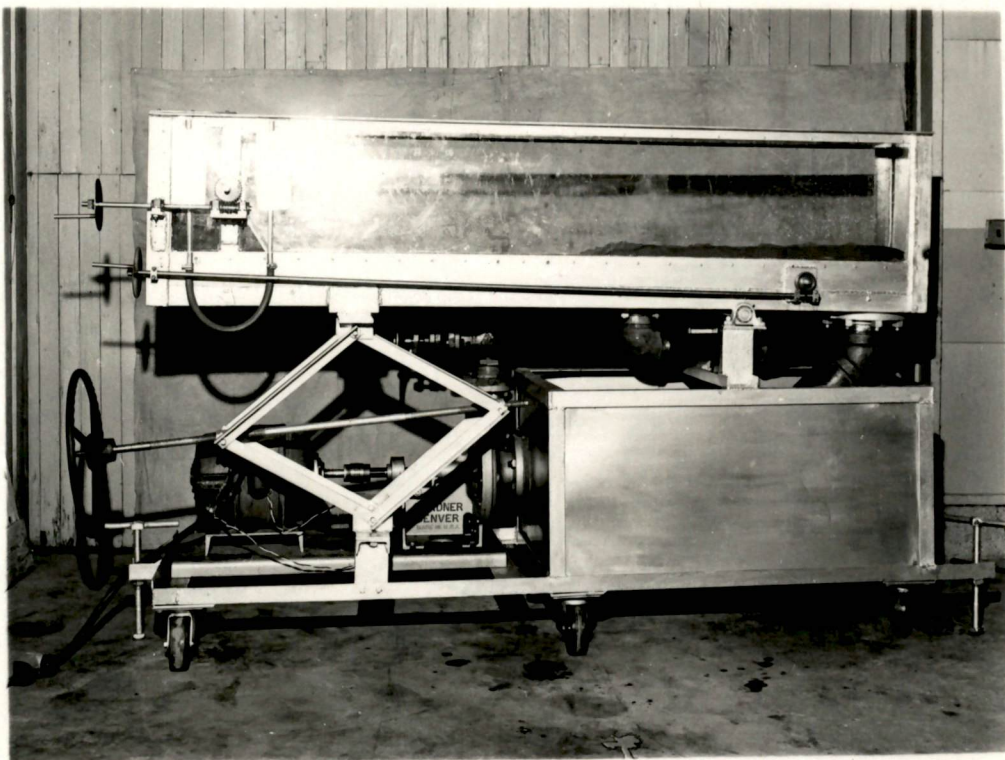


Figure 11. Channel in operation with small hydraulic jump.

3. Differential pressures
4. Buoyance
5. Use of manometers
6. Flow net patterns
 - a. Effects of obstructions in channels

II. Fundamentals of water flow

1. Laminar flow
2. Turbulent flow
3. Uniform flow
4. Non-uniform flow
5. Continuity of flow
6. Energy and head (Bernoulli theorem)
7. Hydraulic gradient
8. Energy gradient
9. Slope-velocity relationships
10. Velocity measurements
11. Measurement of power and kinetic energy
12. Use of flow meters

III. Open-channel flow

1. Steady and unsteady flow
2. Elements of cross-sections
(Use of Manning's formula)
3. Critical flow
4. Hydraulic jump
5. Roughness coefficients
 - a. Effects of vegetation

- b. Effects of obstructions in channels
(Flow net patterns)

- 6. Critical velocity (Surges)

- IV. Pipe flow*

- 1. Friction losses
- 2. Other losses
 - a. Entrance
 - b. Enlargement
 - c. Contraction
 - d. Obstruction
 - e. Bend
- 3. Roughness coefficients

- V. Orifice flow

- 1. Entrance versus jet velocities

- VI. Weir flow

- 1. Types of weirs
 - a. Submerged and overflow
 - b. Effects of ventilated and unventilated nappes
 - c. Velocity of approach
 - d. Discharge coefficient
- 2. Chutes
- 3. Spillways

*Use of the channel in pipe flow discussions would necessitate the installation of pipes within the channel. This could be readily done by mounting the desired pipe through a hole in a wall placed across the stream in the model installation devices.

VII. Other

1. General use of models
2. Dams, to illustrate such items as flood routing
3. Use of flow meters, pitot tubes, and other instruments allied with other subjects

B. Research

I. Design of agricultural water control structures

1. Weirs, flumes, spillways, chutes, dams
2. Various sizes, shapes, slopes, heights, aprons, and baffle size and location, etc.

II. Calculation of roughness coefficients for various surfaces

1. Effects of vegetation

III. Silt or sedimentation studies

IV. Calculation or measurement of friction losses

1. In pipes (Use Darcy-Weisbach resistance

$$\text{equation: } f = \frac{(h_1 - h_2) 2Dg}{LV^2})$$

2. In open channels (Use alternative form of

$$\text{Darcy-Weisbach equation: } f = \frac{(h_1 - h_2) 8Rg}{LV^2})$$

A Teaching Demonstration: To Show How the Channel Model May Be Used in Presenting a Demonstration of the Transition from Laminar to Turbulent Flow

Reynolds Demonstration: When a certain critical Reynolds number is exceeded, laminar flow reaches such a state of unstable equilibrium that a particular frequency range of a local disturbance produces the

haphazard secondary motion called turbulence. About seventy years ago Reynolds demonstrated this phenomenon by means of the tank, dye injector, and transparent glass tube shown schematically in Figure 12.⁽¹²⁾ This apparatus could quite easily be installed in this channel and used as a classroom demonstration.

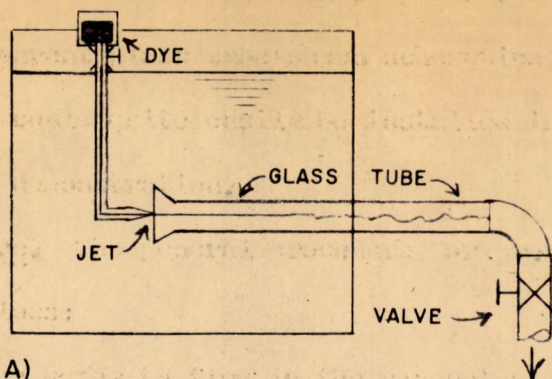
Procedure. The general procedure for presenting this demonstration is as follows:

Allow the water to flow in the channel at a sufficiently low rate to insure laminar flow conditions. Open the valve on the dye injector to inject a filament of dye into the bell inlet. Observe that this filament extends the entire length of the glass tube without noticeable diffusion. This condition indicates completely laminar flow.

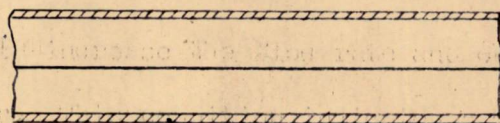
Gradually increase the flow rate and observe that the filament begins to waver. This condition indicates a borderline between laminar flow and turbulence. Note that a further gradual increase in flow rate causes the dye filament to disintegrate eventually at some intermediate section, beyond which the dye spreads rapidly over the entire tube cross-section. This condition indicates turbulent flow.⁽¹²⁾

A Laboratory Problem: To Calculate the Rate of Flow Over a Submerged Sharp-crested Weir

The Problem. A sharp-crested weir shall be installed in the bottom of the channel and water allowed to flow over it at various rates. After measurements are made of weir width, weir height, and piezometric head, rate of flow may be calculated. The weir must span the channel entirely, and the space under the weir nappe must be ventilated to obtain accuracy of measurements.⁽¹²⁾



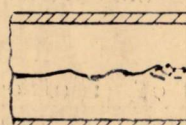
(A)



(B)



(C)



(D)

Figure 12. Reynolds
to turbulent flow.(12)

in laminar

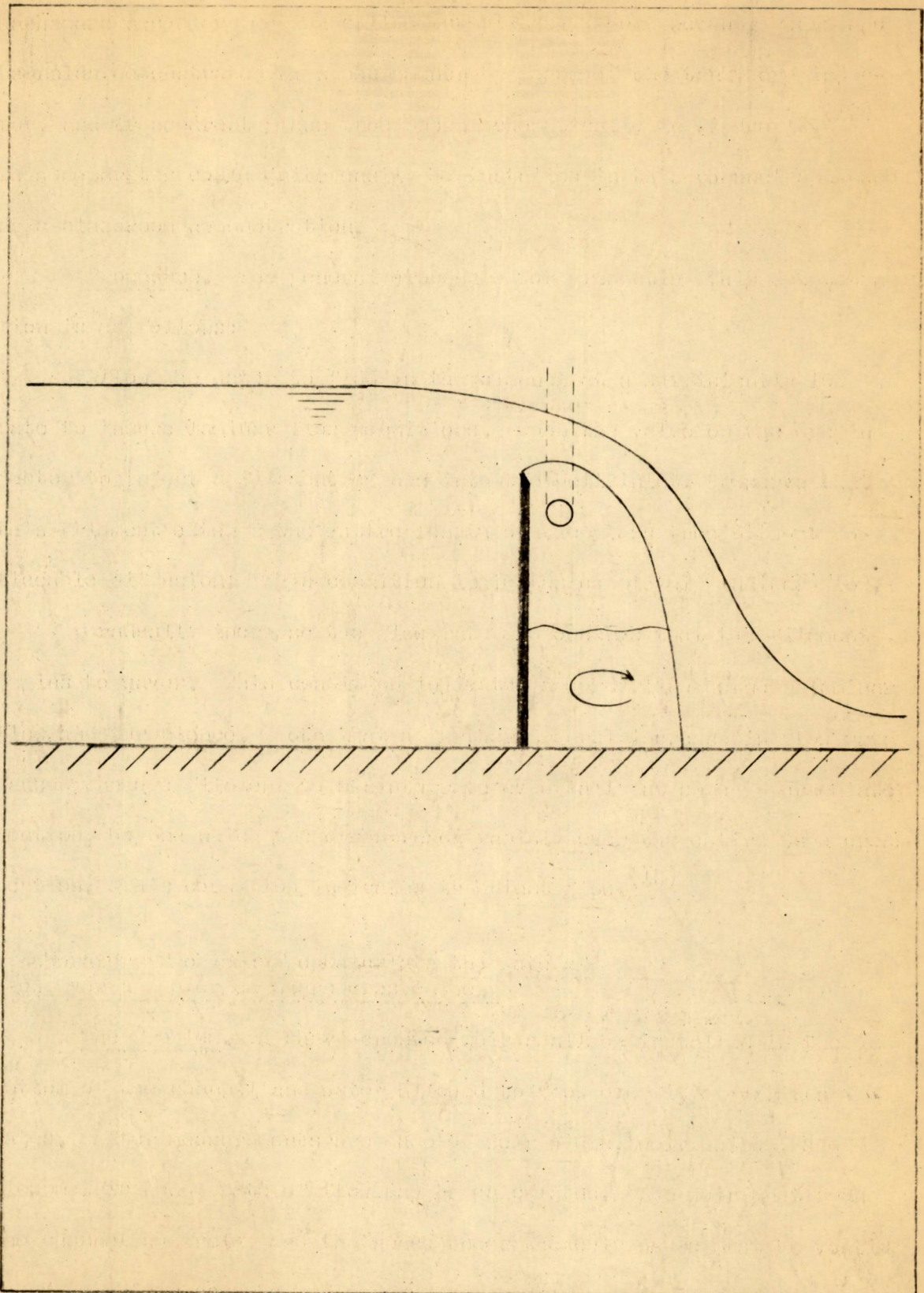


Figure 13. Flow over a sharp-crested weir with ventilated weir nappe. (12)

Equations Used. Although not entirely accurate, but sufficiently accurate for acceptance, the following equations may be used: (12)

$$C_d = 0.611 + 0.075 \frac{h}{w} \quad (\text{Equation 1})$$

$$Q = C_d (2/3) \sqrt{2g} Lh^{3/2} \quad (\text{Equation 2})$$

In these equations

h = piezometric head

w = weir height

C_d = coefficient of discharge

g = acceleration of gravity

L = width of weir

Q = rate of flow, cubic feet per second

Procedure. Measure accurately the weir height and width. Install hook gages within the channel for measurement of water depths. Establish steady flow at a low rate and make hook gage reading. Subtract weir height from this reading to determine piezometric head value.

Calculate the discharge coefficient by the use of equation one. Using this value, calculate quantity of flow by use of equation two.

Make several replications to insure accuracy.

Repeat the procedure for various flow rates.

A Research Problem: To Design an Energy Dissipation Structure

Types of Structures. This suggested problem could include more than one type of structure. Such energy dissipators for agricultural water as weirs, chutes, flumes, and spillways all give the research-minded

ample opportunity for investigation. Not only could various arrangements of one type, such as spillways, be experimented upon, but also comparisons between two types might be worthwhile.

Limitations of This Project. It must be pointed out that any data gathered on this type of experiment will be qualitative, not quantitative. Comparisons or relative values obtained should provide a reasonably accurate conclusion. However, due to limiting conditions, such as extremely short channel length compared to its width, it will be impossible to obtain accurate values. It is the author's belief, however, that many worthwhile comparisons can be made with this type of research.

Functional Requirements. In the design of the structures mentioned above, two basic functional requirements must be met: (1) the structures must have sufficient capacity to pass the design discharge, and (2) the kinetic energy of the discharge must be dissipated within the confines of the structure in a manner and to a degree that will protect the structure as well as the downstream channel from damage.

Design Problem. To illustrate how the channel may be used for research purposes, an example will be presented using the design of a rectangular spillway as the problem. However, the same general approach would apply to other types of structures previously mentioned.

Design several spillways with various combinations of dimensions. Alter only one variable at a time. For example, with all other dimensions held constant, various apron lengths or various baffle arrangements--number, size, shape, or positions--can be experimented with.

Allow water to flow over each structure at various rates.

Results. Make observations of flow over each structure to obtain a comparison of energy loss with each. Determine which design produces the least turbulence below the structure.

If desired, soil or sand may be placed in the channel immediately below the apron. A trap must then be installed to catch this material during each run, after which the soil will be weighed. This test will give a reasonably accurate indication of degree of scouring for each structure.

Prototype structures may not give exactly the same results as these models. However, results of model tests and prototype tests should be similar.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

An attempt has been made in this project to design and to construct a satisfactory hydraulic demonstration channel for use in teaching and research. A hydraulic demonstration channel eight feet long, twelve inches wide, and eighteen inches deep with a pump capacity of three hundred gallons per minute has been constructed. This channel can be used for the effective teaching of practically any phase of elementary fluid mechanics and many aspects of stream flow. Although most results will be qualitative rather than quantitative, uses in research are unlimited. However, before the channel can be fully utilized, its calibration is necessary. As a result of some experiences encountered in the construction of the model, some design changes are suggested in Chapter IX.

It has been the author's purpose to make a simple and economical design that could be duplicated by other agencies operating with a limited budget and could be constructed by semi-skilled workers. The objectives discussed in Chapter II have been reasonably well fulfilled. Simplicity, one of the major objectives, has been maintained by use of few parts which cannot be fabricated in shops of such agencies as university departments of agricultural engineering. Economy, the second major objective, has also been maintained. Exclusive of labor, the total cost of this project was about seven hundred fifty dollars. Including labor, total cost is estimated at approximately one thousand

dollars. The manufacturer of the ARS model, which is considerably smaller than the one developed in this project, quoted a price of over eighteen hundred dollars plus freight. Therefore, the author concludes that the model reported in this manuscript has the advantage of greater capacity plus a savings of over eight hundred dollars.



CHAPTER IX

RECOMMENDATIONS

Design Alterations

The author realizes that certain features in this design could be improved. Construction difficulties indicated certain inadequacies that should be corrected. Therefore, the following changes, not necessarily listed in order of importance, are suggested:

1. Thinner metal could be used in the channel. The three-sixteenths inch sub-channel walls could be reduced to a thickness of five-thirty-seconds inch.
2. An additional two feet of channel length would improve the use of the channel in presenting stream flow. Also, placing this extra length on the tail end would provide additional counter-weight to make jacking easier.
3. The jack should be placed under the channel center-line rather than to one side. This could be accomplished by moving the pump and motor farther to one side and moving the channel farther to the other side.
4. A small drain plug should be installed in the slope indicator tube to facilitate drainage when necessary.
5. A drain plug should be installed in the sub-channel to allow complete drainage when necessary. Removal of the hose is the only method provided at present.

6. A stilling-well and hook-gage mechanism should be installed to facilitate flow measurement by use of weirs or similar devices.
7. Placing rubber strips on the sides of both gates would eliminate leakage around the gates and give better control of water flow.
8. A baffle should be placed in the tank between the inlet and the discharge to reduce the quantity of air pumped into the channel.

Future Study

The author recommends that further study be pursued in any of the research areas mentioned in Chapter VII. It seems to the author that any one of these subjects would be an excellent project for a graduate student's research work.

Probably the first work that should be done is calibration. Satisfactory calibrations of quantity of flow and velocity of flow are necessary before extensive research work is begun.



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BIBLIOGRAPHY

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APPENDIX A

CRANES  CREST

COST SUMMARY

Item	Quantity	Dimensions	Cost
Plexiglass	2 sheets	1/2" x 18" x 96"	\$94.09
Plexiglass	1 sheet	1/4" x 12" x 43 7/8"	7.49
Plexiglass	1 sheet	1/4" x 12" x 31 7/8"	5.45
Angle iron	40'	1/4" x 2" x 2"	14.28
Sheet steel	2 sheets	16 gauge x 4' x 8'	17.68
Steel plate	1 sheet	3/8" x 12" x 24"	3.56
Steel plate	1 sheet	10 gauge x 24" x 24"	2.51
Steel plate	1 piece	1/4" x 12" x 20'	34.46
Steel plate	1 piece	3/8" x 4" x 20'	16.43
Steel plate	1 piece	3/8" x 2" x 20'	5.72
Pump	1	4" intake, 3" discharge 300 gpm	174.50
Electric motor	1	5 Hp, 230 volts, 60 cycle, 1760 Rpm	122.36*
Casters	2	6" swivel, rubber base, Bassick #H6999-2	18.94
Casters	4	6" swivel, rubber base, Bassick #H6999-2	37.88*
Gate valve	1	3" Jenkins #325	55.10

*These items were not purchased but were in stock in shops of University of Tennessee Department of Agricultural Engineering. Prices shown are those quoted by local dealers.

COST SUMMARY (continued)

Item	Quantity	Dimensions	Cost
Pipe flanges	1	6" companion	\$ 5.44
Pipe flanges	2	4" companion	7.10
Pipe flanges	2	3" companion	4.87
Pipe elbow	1	6"-60°	12.32
Pipe elbow	1	4"-90°	4.40
Pipe elbow	1	3"-90°	3.68
Pipe nipple	1	6" x 3"	1.37
Pipe nipple	1	4" x 8"	2.96
Pipe nipple	1	4" x 3"	1.57
Pipe nipples	3	3" x 3"	2.65
Pipe	1	6" x 18"	5.31
Pipe	1	3" x 17"	1.86
Gasket material	3 lb.	1/8"	2.16
Worm gear	1	Boston Catalog #G1051	5.85
Worm gear	1	Boston Catalog #G1061	6.80
Worm	1	Boston Catalog #GH1056	2.38
Worm	1	Boston Catalog #GH1066	3.87
Thrust washers	4	Bronze, I.D. 5/8", O.D. 1 3/16", Thickness 3/32"	2.40
Thrust washers	2	Bronze, I.D. 1/2", O.D. 1", Thick- ness 1/16"	1.18

COST SUMMARY (continued)

Item	Quantity	Dimensions	Cost
Machine screws	1 gross	10-24 x 1/2", R.H.	\$ 1.50
Machine screws	1 gross	10-24 x 3/4", R.H.	1.05
Weatherstrip sealer	50'	"Shur-Stik" 5/32" x 1/2"	2.74
Packing	2 pkgs.	Valve stem packing	0.50
Plastic tubing	6'	Tennite II Butyrate, colorless trans- parent, I.D. 1/2", O.D. 5/8"	2.52
Rubber hose	2'	I.D. 5/8"	0.32
Rubber hose	4'	I.D. 3"	10.32
Hose clamps	4	3" adjustable	2.40
Hose clamps	2	5/8" adjustable	0.60
Nuts	2	1", left hand thread	0.70
Nuts	2	1", right hand thread	0.70
Ethylene dichloride	1 qt.		2.50
Plastic cement	1 pt.	Acryloid B-7	1.75
Miscellaneous (bolts, washers, cotter pins, keys, etc.)			<u>5.00</u>
		Total	\$721.22



APPENDIX B

SCHEDULE OF PARTS

Part Number	Description	Number Required	Drawing Sheet	Material
BASE ASSEMBLY:				
1	Frame Member, Sides	2	16	Steel
2	Frame Member, Cross	3	16	Steel
3	Caster Mounting Plate	6	16	Steel
4	Castors	6	--	Rubber-tired
5	Bolts, Leveling, with Nuts	3	16	Steel
6	Nuts, with Cross Arms	3	16	Steel
7	Frame, Leveling Stand	1	16	Steel
PUMP, MOTOR				
8	Pump	1	3	--
9	Motor	1	3	--
10	Support Plate	1	3	Steel
11	Cross-Members	2	16	Steel
TANK:				
12	Frame Member, Upright	4	1	Steel
13	Frame Member, Sides	2	1	Steel
14	Frame Member, Ends	2	1	Steel
15	Sides and Bottom	1	2	Steel
16	End, with Pump Hole	1	2	Steel
17	End, Plain	1	2	Steel
18	Gate Valve	1	--	--

SCHEDULE OF PARTS (continued)

Part Number	Description	Number Required	Drawing Sheet	Material
PUMP INTAKE:				
19	Pipe Flange, 4"	1	--	C.I.
20	Companion Flange, 4"	1	--	C.I.
21	Pipe Nipple, 4" x 4"	2	--	C.I.
22	Pipe Nipple, 4" x 8"	1	--	C.I.
23	Pipe Elbow, 4"	1	--	C.I.
PUMP DISCHARGE:				
24	Pipe Flange, 3"	2	--	C.I.
25	Pipe Nipple, 3" x 4"	3	--	Steel
26	Pipe Elbow, 3"	3	--	Steel
27	Gate Valve, 3"	1	--	--
28	Hose, Flexible, 3" x 4'	1	--	Rubber
29	Hose Clamps	4	--	Steel
30	Pipe, 3" x 17"	1	--	Steel
CHANNEL SUPPORT:				
31	Channel Pivot Support	1	6	Steel
32	Channel Pivot Support Legs	2	6	Steel
33	Bearing Plates	2	6	Steel
34	Bearing Assemblies	2	6	--
35	Swivel Rod, 1" x 17 1/2"	1	17	Steel
CHANNEL DISCHARGE				
36	Pipe Flange, 6"	1	--	C.I.

SCHEDULE OF PARTS (continued)

Part Number	Description	Number Required	Drawing Sheet	Material
37	Pipe Nipple, 6" x 4"	1	--	Steel
38	Pipe Elbow, 45°	1	--	Steel
39	Pipe, 6" x 18"	1	--	Steel
JACK SUPPORT:				
40	Base Member	1	4	Steel
41	Legs	2	4	Steel
JACK:				
42	Frame Members	3	5	Steel
43	Frame to Channel Members	2	17	Steel
44	Legs, Frame Members to Pivots	4	5	Steel
45	Jack Frame	8	5	Steel
46	Jack Pivot Support, with Nuts	2	4	Steel
47	Jack Pivot Support, Plain	2	4	Steel
48	Jack Screw Shaft	1	5	Steel
49	Jack Crank (Truck Steering Wheel)	1	--	--
CHANNEL:				
50	Sub-channel Frame Members	2	17	Steel
51	Sub-channel Floor	1	17	Steel
52	Sub-channel End	1	17	Steel
53	Channel Base Walls	2	17	Steel
54	Channel Floor	1	17	Steel

SCHEDULE OF PARTS (continued)

Part Number	Description	Number Required	Drawing Sheet	Material
55	Channel Wall	1	18	Plexiglass
56	Channel Wall	1	18	Plexiglass
57	Channel Floor Covering	1	18	Plexiglass
58	Ends	2	7	Steel
59	Corner Braces	4	7	Steel
60	Corner Spacers	4	7	Steel
61	Upper Side Rails	2	7	Steel
LEVEL INDICATOR:				
62	Tubes, Clear, 1/2" I.D., 5/8" O.D.	2	8	Plastic
63	Hose, 5/8" I.D.	1	--	Rubber
64	Indicator Plates	2	8	Steel
TAILGATE:				
65	Gate	1	13	Aluminum
66	Shaft, Tailgate Pivot	1	12	Bronze
67	Support Block	1	10	Steel
68	Worm Gear	1	14	C.I.
69	Worm	1	14	Steel
70	Shaft Support Block	2	9	Steel
71	Shaft Support Block	1	11	Steel
72	Shaft, Control	1	12	Steel
73	Crank Wheel	1	15	Steel

SCHEDULE OF PARTS (continued)

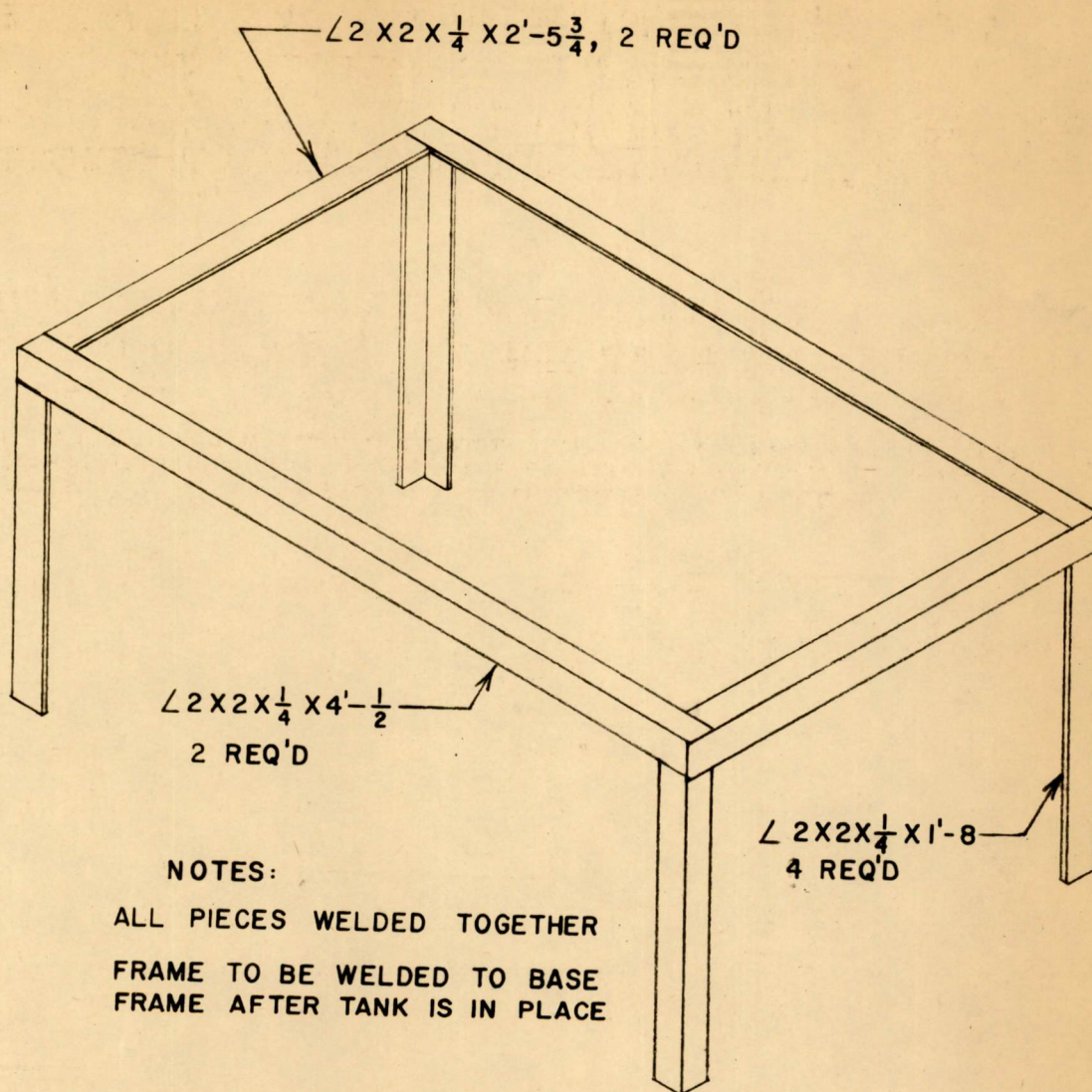
Part Number	Description	Number Required	Drawing Sheet	Material
HEADGATE:				
74	Cover	1	19	Steel
75	Bonnet	1	10	Steel
76	Gate	1	19	Aluminum
77	Shaft, Headgate Pivot	1	21	Bronze
78	Ball Bearing	2	21	--
79	Control Shaft Support, Front	1	21	Steel
80	Control Shaft Support, Rear	1	23	Steel
81	Worm and Pillow Block Support	1	22	Steel
82	Pillow Block, Boston Gear Catalog #SRP10	3	20	C.I.
83	Removable Gate Shaft Support, Back	1	22	Steel
84	Fixed Gate Shaft Support, Front	1	22	Steel
85	Bearing Block	3	20	Steel
86	Bearing Cover Plate	1	20	Steel
87	Worm Gear	1	21	C.I.
88	Worm	1	21	Steel
89	Shaft, Headgate Control	1	20	Bronze
90	Collar	1	20	Bronze
91	Crank Wheel	1	20	Steel
92	Dial Indicator	1	21	Steel

SCHEDULE OF PARTS (continued)

Part Number	Description	Number Required	Drawing Sheet	Material
93	Dial Indicator Plate	1	21	Steel
94	Bonnet Support	1	23	Steel
95	Bonnet Support	1	19	Steel
96	Gasket Retainer Strips	3	22	Aluminum
Miscellaneous Items Such as Bolts, Nuts, Screws, Washers, Cotter Pins, Gaskets				

APPENDIX C

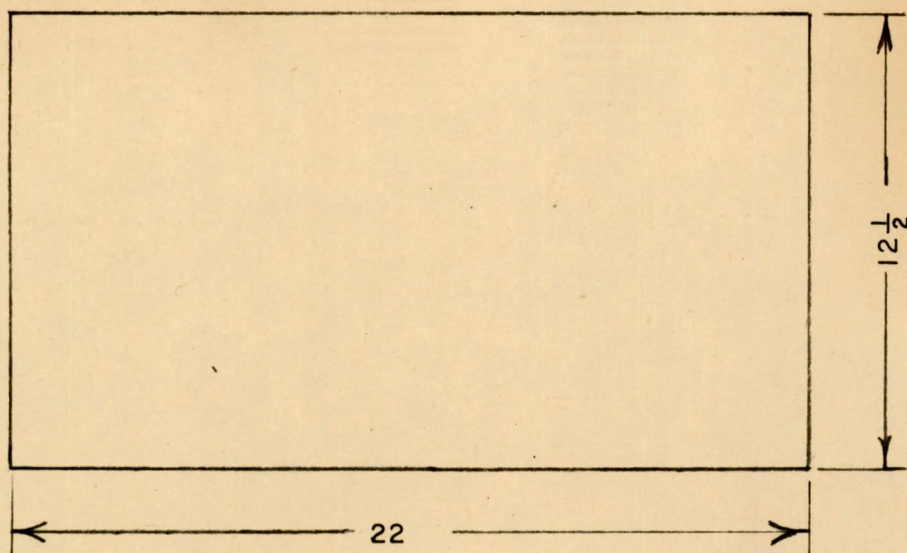
SHEET 1



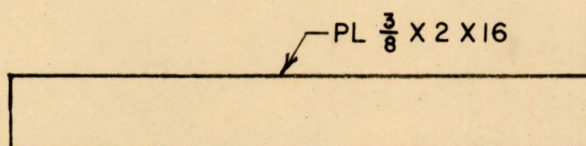
OUTSIDE TANK FRAME

SCALE: 1" = 1'

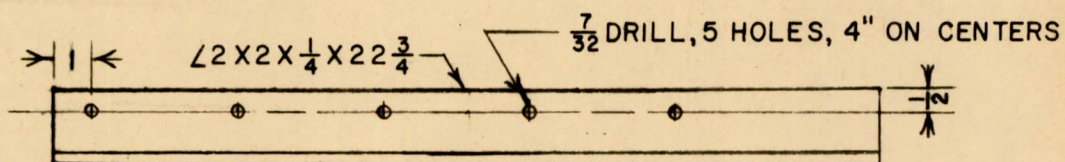
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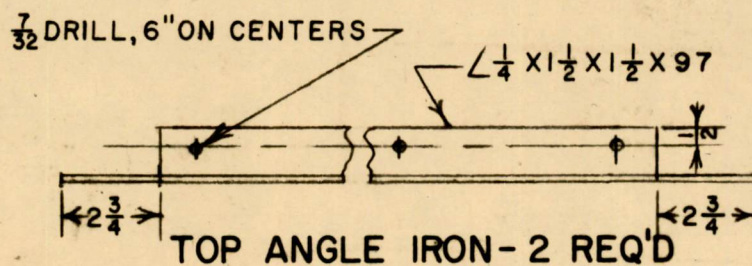
$\frac{1}{4}$ " END PLATE - 2 REQ'D



SPACER - 4 REQ'D



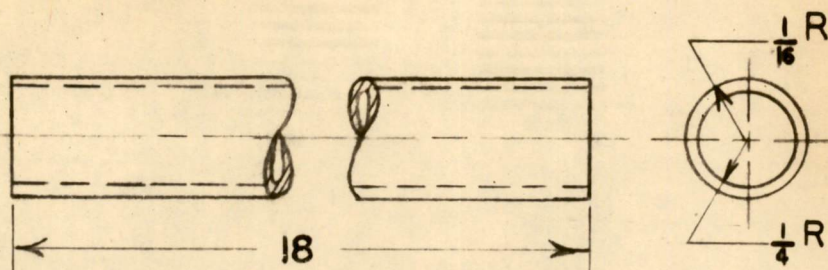
END ANGLE - 4 REQ'D



TOP ANGLE IRON - 2 REQ'D

SCALE: $\frac{3}{16} = 1$

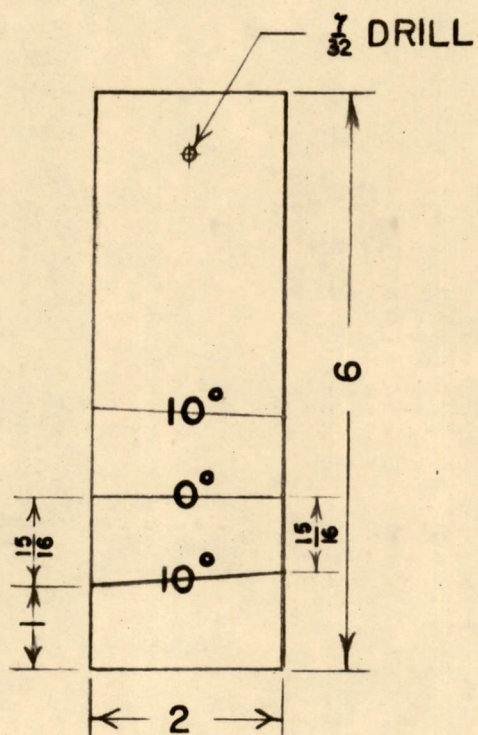
SHEET 8



TENNITE LEVELING TUBE

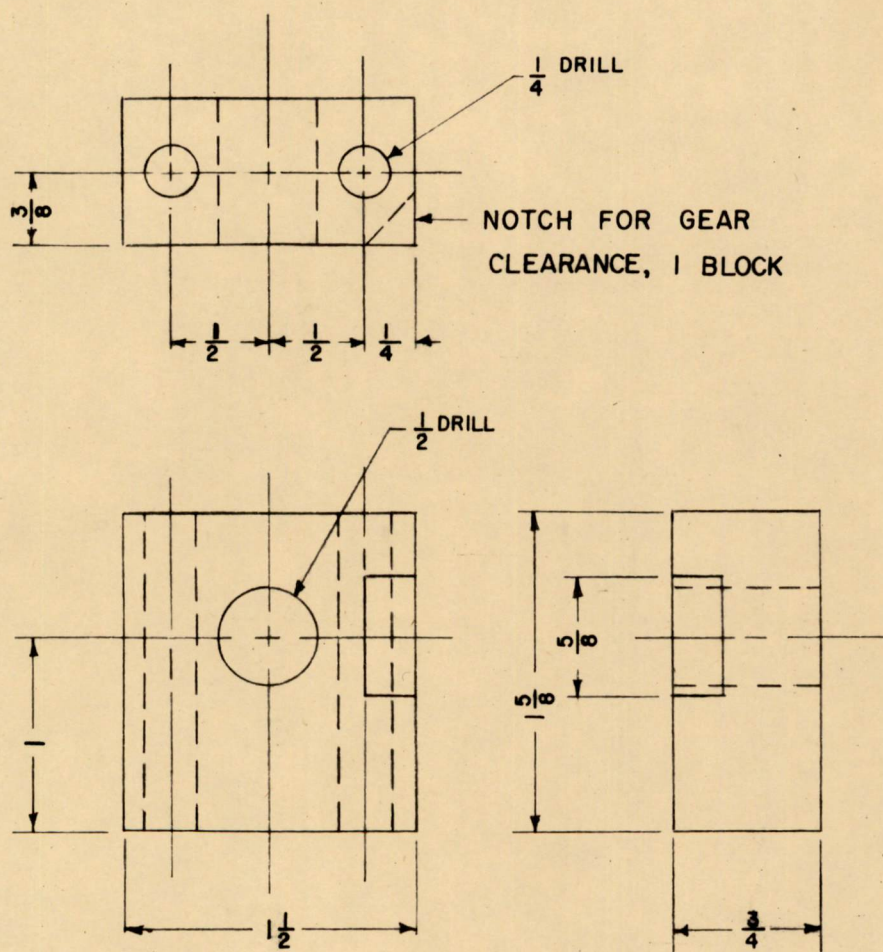
2 REQ'D

SCALE: FULL

LEVELING INDICATOR
2 REQ'D.

SHEET METAL

SCALE: HALF

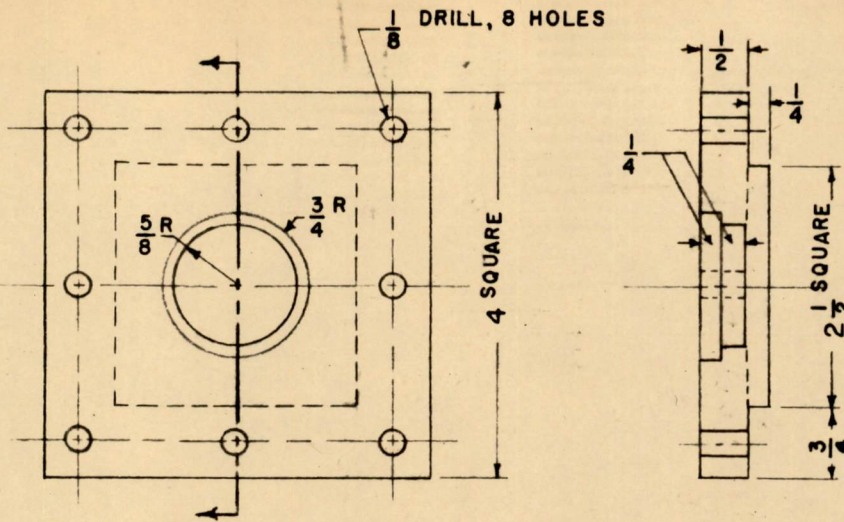


SHAFT SUPPORT BLOCK

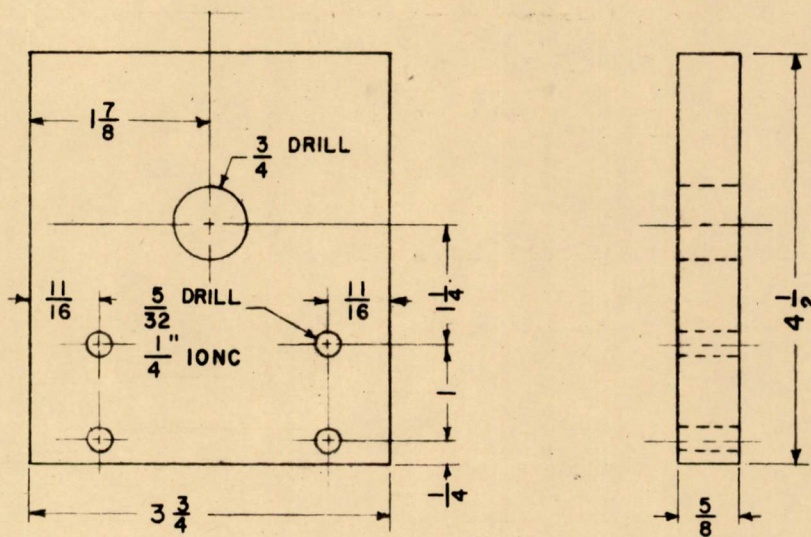
2 REQ'D

SCALE: 1 = 1

SHEET 10



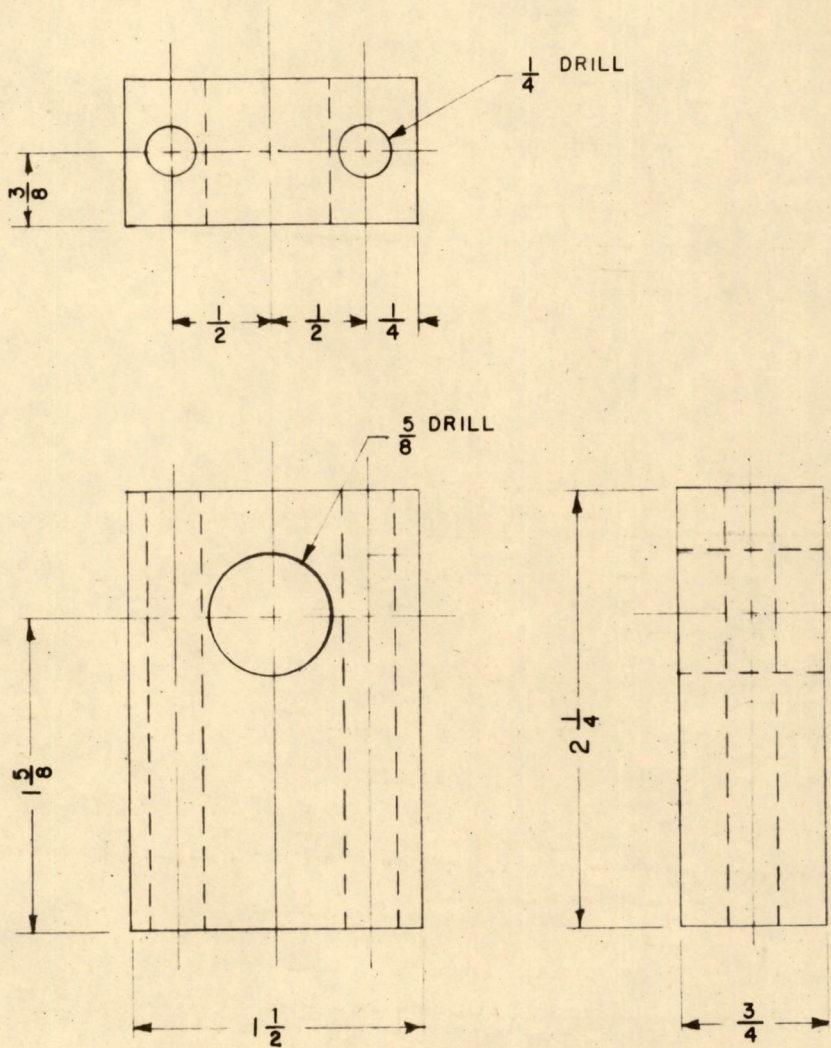
HOUSING BLOCK



HOUSING AND SUPPORT BLOCK

SCALE $\frac{1}{2} = 1$

SHEET II

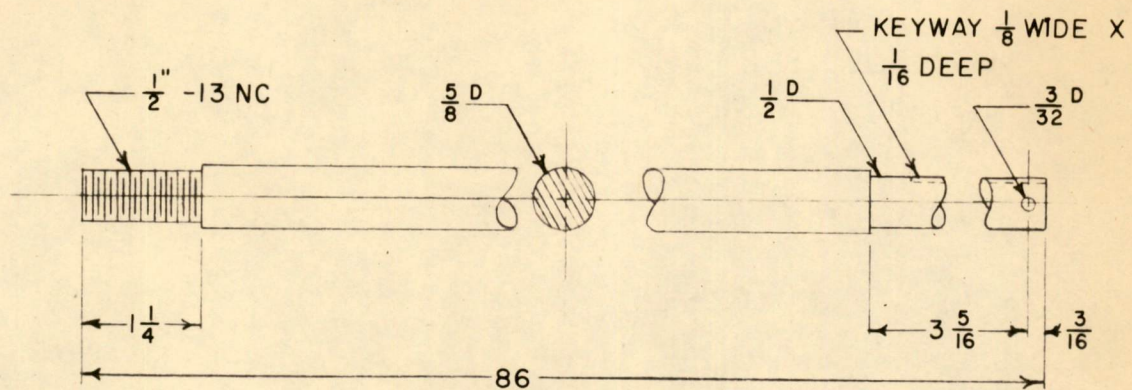


SHAFT SUPPORT BLOCK (FRONT)

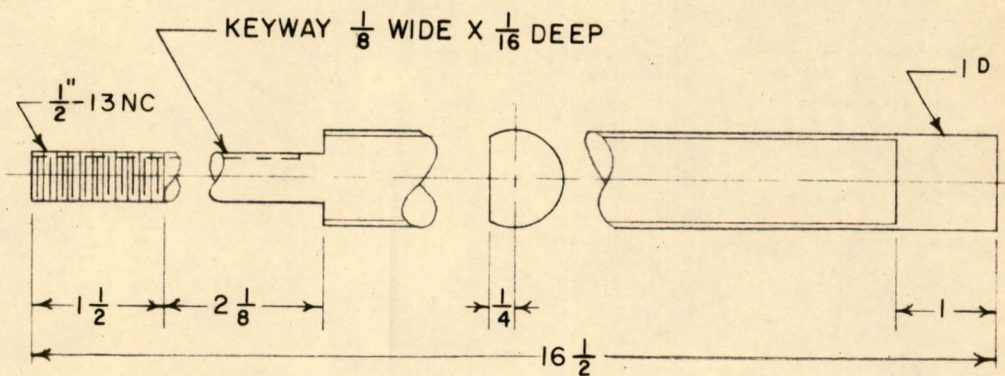
2 REQ'D

SCALE: 1=1

SHEET 12



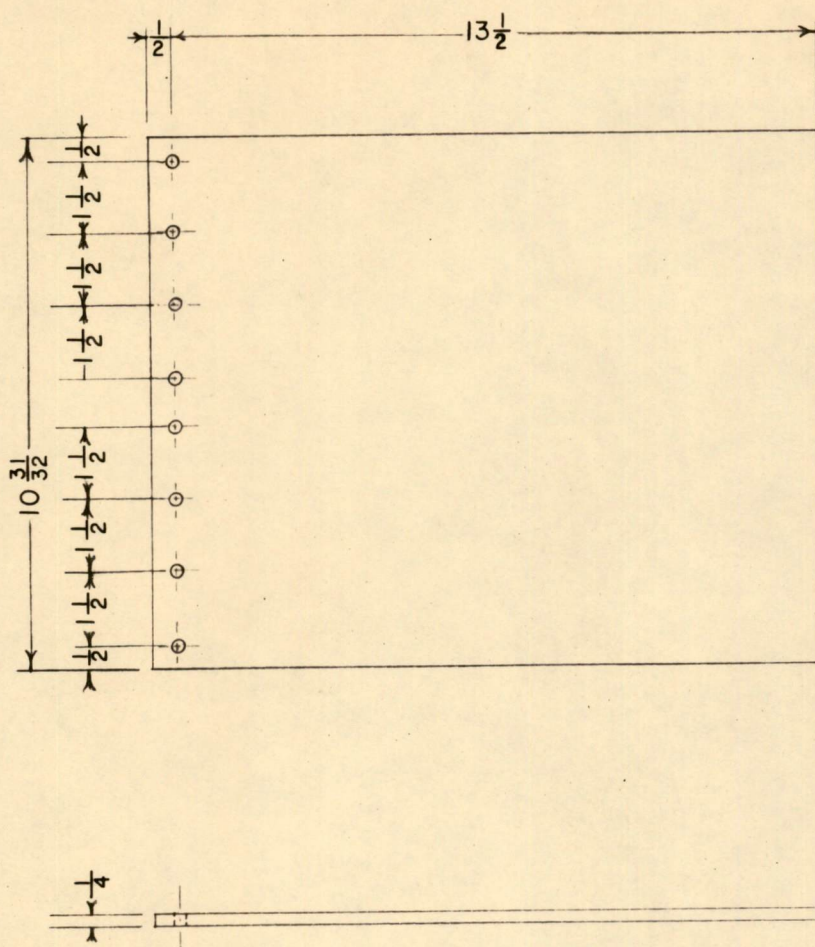
TAILGATE CONTROL SHAFT



TAILGATE PIVOT SHAFT

HALF SCALE

SHEET 13



TAILGATE

SCALE: $\frac{1}{4} = 1$

