



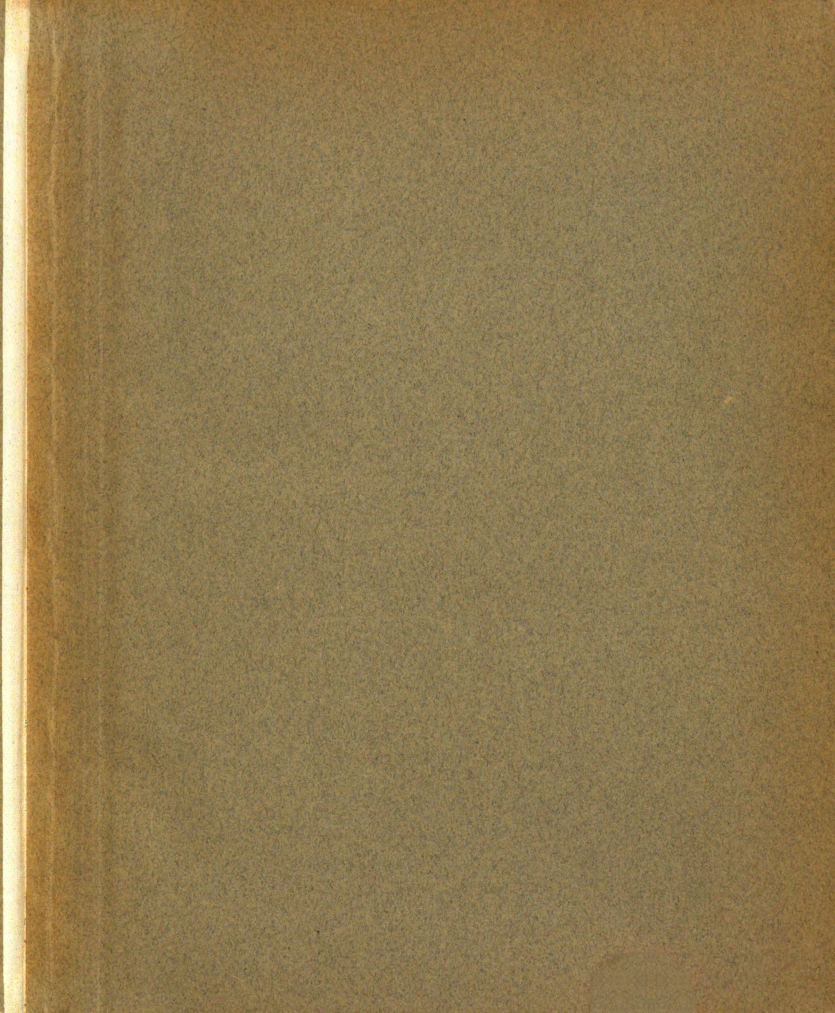
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AUTOMATIC SPILLWAY GATES
FOR ICE AND NON-ICE
CONDITIONS

THESIS FOR THE DEGREE OF B. S.
R. W. Becker
1934

THESIS

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Automatic Spillway Gates for Ice
and Non-ice Conditions

A Thesis Submitted to
The Faculty of
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By

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Candidate for the Degree of
Bachelor of Science

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To the Detroit Edison Company for kindness shown at their Geddes Plant and Ann Arbor Office.

INTENT

This paper is intended to be a brief summary of automatic spillway gates that have been, or are now being used with a fair degree of success. It is further intended to treat lightly ice conditions and methods of controlling them, especially in conjunction with the automatic gate. A new idea for an automatic crest gate will be worked out in the rough to illustrate what might be a useful principle in automatic gating in the future.

AUTOMATIC GATES

Introduction

The following definitions will be adhered to in this paper:

An automatic gate is a gate which is operated by the pressure of the standing or flowing water of the stream or pond. Furthermore this pressure must be controllable by a small amount of work for which only a few men and a short time are required.

A purely automatic gate is a gate which is operated by the pressure of the standing or flowing water of the stream or pond. Furthermore this pressure must be controllable by a mechanism responding to predetermined elevations of the head-water. This gate must be capable of operating without the presence of an attendant.

Throughout this paper references will be mentioned by the numbers they bear in the bibliography.

In order to maintain simplicity, the Fargo Classification (Ref. 24) will be followed. All gates other than automatic or purely automatic will be mentioned but briefly.

The Fargo Classification

- I Needle Dams
- II Sliding Gates
 - A. Crest
 - B. Deep Sluice
- III Pivoted or Hinged Gates and Flashboards
 - A. Bear Trap Gates
 - B. Tainter, Sector, and Drum Gates
- IV Rolling Gates
 - A. Cylinders
 - B. Shutters of polygon section mounted between large wheels or rollers which travel inclined racks
- V Siphon Spillways

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PART I

Gates

Needle Dams

The needle dam is used most extensively in European countries. It cannot be classed as an automatic gate due to the large amount of labor required to operate it. The chronological order of development is:

Poiree's Needles	1834	Vertical needles
Boule Gates	1874	Square sections
Curtain Dams	1876	Horizontal needles

(Ref. 9 & 26)

Sliding Crest Gates

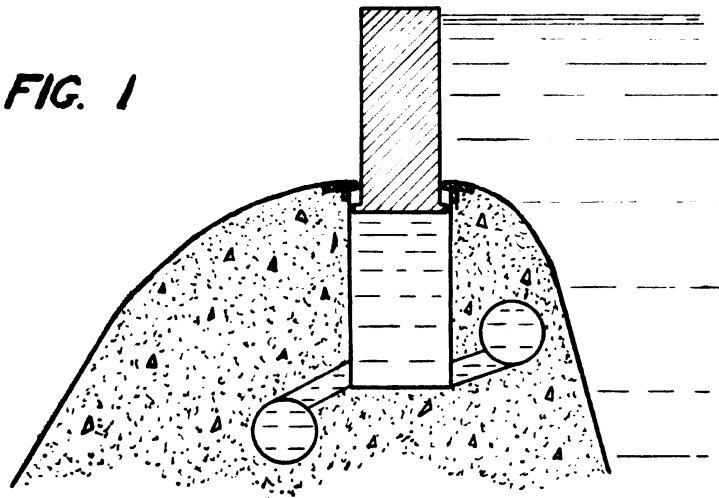
The stoney gate and similarly constructed gates, operated by overhead cranes and hoists, are the most common sliding crest gates of today. They are obviously not automatic. There have been automatic sliding crest gates designed, however. A good example is the Stickney Lifting Dam, designed by Lieut. Col. Amos Stickney, Corps of Engineers, U.S.A. for closing the navigable pass at Dam #6 on the Ohio river. The principle of construction of this gate is illustrated in Fig. 1.

The gate is raised by the pressure of the water stored in a reservoir upstream of the dam. The stops, as shown, prevent the gate from leaving the chamber. The gate is lowered by closing the valve leading to the reservoir, and opening a valve to the stream below the dam. The gate drops by its own weight. The reservoir can be filled by natural flow when the river is at high stage.

The Stickney gate is not always able to operate as an automatic gate. This is true when for some reason, such as an emergency, the water must be pumped into the reservoir. Thus, a pump should be a part of the equipment. The Stickney gate has the following characteristics:

- a. Rapidity of movement
- b. Small leakage
- c. Automatic operation
- d. Can operate under any condition of the river
- e. Provides for safety of the operators

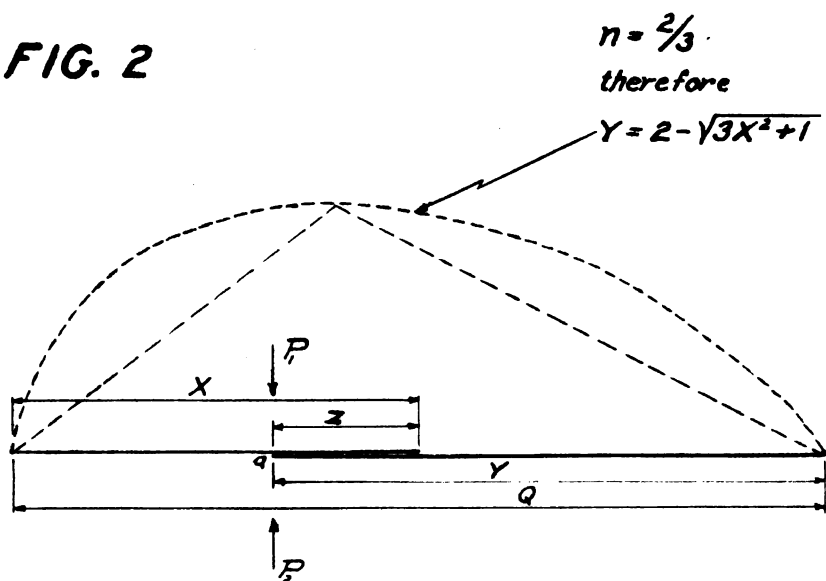
FIG. 1



Vertical Section

STICKNEY LIFTING DAM

FIG. 2



LINE DIAGRAM FOR "OLD BEAR TRAP"

Sliding Gates for Deep Sluices

Although gates of this nature are very extensively used, they are not of an automatic character. There are many different types of sliding gates for deep sluices, among which are some of the following:

- a. Stoney gates (Ref. 2 & 27)
- b. Multiple Leaf gates (Ref. 1)
 - 1. Old type, multiple slot
 - 2. Cantilever type
 - 3. Guillotine type
- c. Sliding gates with ice-flaps (Ref. 1)
- d. Broome gates (inclined) (Ref. 27)
- e. Sliding Vertical Cylinder gates (Ref. 27)

Pivoted or Hinged Gates and Flashboards

Bear Trap Gates

The bear trap gates have been about the most successful of the automatic gates, and therefore merit considerable attention. The chronological order of their development is as follows:

1819	Old Bear Trap	Shown in Fig. 3
1862	Du Bois Gate	Shown in Fig. 4
1868	Girard Gate	Shown in Fig. 5
1870	Carro Gate	Shown in Fig. 6
1881	Du Bois Apron Gate	Shown in Fig. 7
1887	Parker Gate	Shown in Fig. 8
1890	Lang Gate	Shown in Fig. 9
1892	Reversed Parker Gate	Shown in Fig. 10
1895	Marshall Gates	Shown in Figs. 11, 12, 13, & 14
1900	Jones Gate	Shown in Fig. 15
1918-1920	Lutz-Hulbert Gate (Have been unable to find a description of this gate)	

Of these gates, the three that are most commonly used in engineering structures are the Old Bear Trap, the Parker Gates, and the Lang Gate. The Parker and Lang gates are best for average conditions, but the Old Bear Trap still has its advantages in remote and inaccessible places where skilled labor and metal work are hard to obtain, and where the expense must be very small.

The Old Bear Trap

History

The first bear trap gate, known as the Old Bear Trap, was invented by Josiah White. He and a business partner found it necessary to make the Lehigh river navigable for business purposes. After considerable study of the situation Mr. White devised a gate to be used in keeping the river at the desired elevation and thereby provide ample draft for his barges.

Theory

The Old Bear Trap is an automatic gate. It consists of two leaves, an upstream leaf and a downstream leaf, and an interior chamber. The chamber is connected to the water above and below the dam by two channels or ducts which may be opened or closed independently of each other by valves. When the upstream valve is opened and the downstream valve is closed, the hydrostatic head above the dam raises the gate. When the upstream valve is closed and the downstream valve is opened, the weight of the gate plus any downward water pressure on the gate will close it. The gate may be held in any intermediate position by the proper adjusting of the valves.

Design

In order to have a workable gate under any given conditions of head and backwater, there are four dimensions which must be related to each other in accordance with certain fundamental laws of mechanics or hydraulics. These are the lengths of the two leaves, the distance between the hinges, and the height to which the dam will raise. For low head conditions, the height which the dam or gate will raise is taken as the basis of design, but in many other cases the distance between the hinges is used because it is limited by cost.

A. O. Powell, U.S. Assistant Engineer, has derived formulas for the Old Bear Trap gate. (Ref. 19) From these formulas he has constructed curves for various head and backwater, from which the four essential dimensions can be taken. If a gate is built, using good engineering practice, to the dimensions of any one curve it will work for the conditions of that curve.

A modification of one of Mr. Powell's curves will be derived and constructed at this point to illustrate the method used in bear trap gate design. To start with, it will be assumed that there is no backwater, and that the leaves have no thickness. The symbols used signify the following: (See Fig. 2)

X = The length of the upstream leaf
Y = The length of the downstream leaf
Z = The overlap when the gate is depressed
Q = The distance between the hinges
H" = The difference in head (upstream and downstream)
P₁ = The downward pressure
P₂ = The upward pressure
w = The weight of a cu. ft. of water

The two critical positions are when the gate is fully elevated and when it is depressed. The case of the gate depressed will be considered first. The downward force which must be overcome is applied on the portion Z only, as the rest of the upstream leaf is between equal pressures.

From hydraulics, water pressure equals the area of the body acted upon times the head at the point of pressure times the unit weight of water. Also from mechanics, the sum of the moments, about any point, of a body in equilibrium equals zero. Therefore P₁ acting through point 'a' is as follows: (See Fig. 2)

$$P_1 = wH'' \left(\frac{XZ - \frac{Z^2}{2}}{X - Z} \right)$$

The upward force used to raise the gate is applied on the whole surface of the downstream leaf. Therefore:

$$P_2 = \frac{wYH''}{2}$$

P₂ also acts through point 'a'. P₂ must exceed P₁, in order to be able to raise the gate. This excess can be definitely fixed to suit given conditions of friction etc. by evaluating 'n' in the following formula:

$$nP_2 = P_1$$

Substituting the values of P₁ and P₂

$$Y = \frac{2XZ - Z^2}{n(X - Z)}$$

By definition:

$$Q = X + Y - Z$$

Substituting and setting Q equal to unity, as it does not effect the relations between X , Y , and Z , the following value or expression for Y can be arrived at:

$$Y = \frac{1 - \frac{n}{2}}{1 - n} - \sqrt{\frac{1}{1 - n} + \frac{1}{4}\left(\frac{n}{1 - n}\right)^2}$$

Also:

$$X = \sqrt{(1 - n)Y^2 - 2Y\left(1 - \frac{n}{2}\right) + 1}$$

At this point ' n ' may be evaluated and the equations for the various curves determined.

Suppose that it is desired to have $1\frac{1}{2}$ times as much lifting force as downward force. If so, ' n ' should be given the value of $2/3$. Therefore by inserting this value in the proper places of the equation for Y , it is found that:

$$Y = 2 - \sqrt{3X^2 + 1}$$

The curve shown on Fig. 2 was constructed from this equation. Any convenient point on this curve will serve as the vertex of the gate, and thereby determine the lengths of X and Y to be used for a given Q . However, the highest point giving the maximum head for a given Q , is usually used, unless there is a definite reason for desiring another point.

It was previously stated that there were two critical positions for the gate. The case of the gate being depressed has been considered, so the next consideration is that of the gate being fully elevated. When the gate is in this position there is one requirement which must be fulfilled. The angle between the leaves must be greater than 90 degrees plus the angle of friction, which means that it must be greater than approximately 100 degrees.

Backwater has not been considered in the above derivation, but could have been entered in by making the expression for P_1 a little more complex.

The specific gravity of the gate may be adjusted one way or the other to some advantage. One leaf may be made buoyant to assist in raising the gate, and the other made heavy to assist in lowering the gate.

In the above derivation it will be noted that the head (H'') drops out, making it appear that the gate will work for any head no matter how small. This may be so from a theoretical standpoint, but it is not true in actual practice. Mr. Powell finds that if the specific gravity is

as low as 1.0, the gate will operate under 6 inches of head or more. As the specific gravity increases the minimum head required becomes greater.

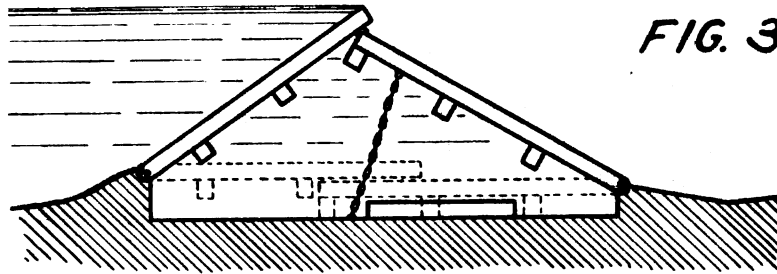
The Later Bear Trap Gates

It is not possible in this short paper to go into each of the successive bear trap gates to any great extent, therefore a brief discussion will be presented in the way of a comparison with the Old Bear Trap gate. All of the later gates operate under the same fundamental laws as Mr. White's gate, and are in a sense of the word merely mechanical improvements or attempts at improvement. For this reason the comparison will be made by showing how they have overcome the various defects or weak points of the Old Bear Trap. These defects will be listed at this stage of the paper and referred to in the discussion by their respective numbers. (See Figs. 3 to 15) The defects are:

- I Friction between the leaves
- II Excessive distance between the hinges (This distance is approximately 3 times the head which can be handled, therefore requiring a sluiceway which is not of economic proportions.)
- III Excessive strain on the leaves (This is due directly to defect II)
- IV Excessive stress at sudden stopping (This requires an extra sturdy structure, increasing the cost.)
- V Warping of the leaves (This is due to the uneven distribution of the water in the chamber when filling)
- VI Driftwood trap (Driftwood and other debris is caught in the exposed exterior angle.)
- VII Overlap of the leaves (Causing impact of the water on the lower leaf.)
- VIII Overlap of the leaves (Causing unnecessary lifting of water.)

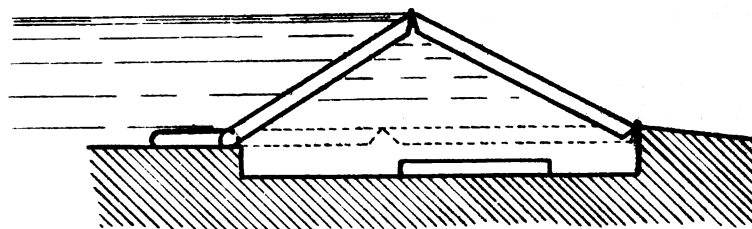
The Du Bois Gate

The Du Bois gate is hardly an improvement over the Old Bear Trap, but will serve as a variation. This gate overcomes defects (I, VI, VII, and VIII), but is subject to an equal amount of criticism for the sliding arrangement of the upstream leaf. This arrangement causes a great deal of friction and is easily clogged by silt, submerged debris, or possibly anchor ice.



Vertical Section

MR. WHITE'S "OLD BEAR TRAP"



Vertical Section

THE DU BOIS GATE

The Carro Gate

M. Carro's gate, being similar to the Du Bois gate avoids the same defects. It also has remedied the clogging difficulty, but introduces more friction and is more complicated to build, thus costing more. So all in all the Carro gate fails to be an improvement, but may be classed as another variation.

The Girard Gate

According to A.O.Powell, the gate patented by M. Girard is the first real improvement of the Old gate. This device has eliminated defects (I,II,III,V,VI, and VIII). The Girard gate, although not properly valued at the time of invention, was the first to have a folding leaf. This feature is the key to the success of the more modern gates.

The Du Bois Apron Gate

Mr. Du Bois' second gate, although introducing a little friction at the foot of the apron, does not have defects (VI and VII). It is heavier and costs a bit more than the Old Bear Trap, but for many conditions may be considered as an improvement.

The Parker Gate

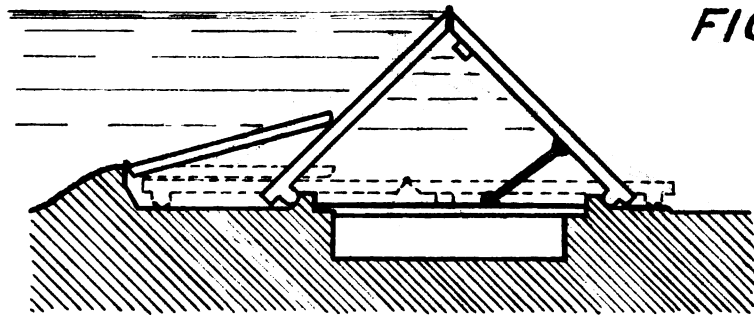
The 'Parker' is in reality Girards' gate turned end for end, with a Du Bois apron added to it. This apron is now called an idler, and provides for the circulation of water through it to avoid unnecessary water pressures. All the defects except (IV) are eliminated in this gate. The absence of defects (II and III) is a very important improvement as the cost of the gate per foot of head is greatly reduced. This enables a stronger and more rigid structure and thereby practically eliminates defect (IV).

A very detailed discussion, including the derivation of formulas, of the Parker gate can be found in A.O.Powell's report in Ref. 19.

The Lang Gate

Mr. Lang substituted chains or rods for part of Mr. Parker's upstream leaf and shortened up on the idler. This

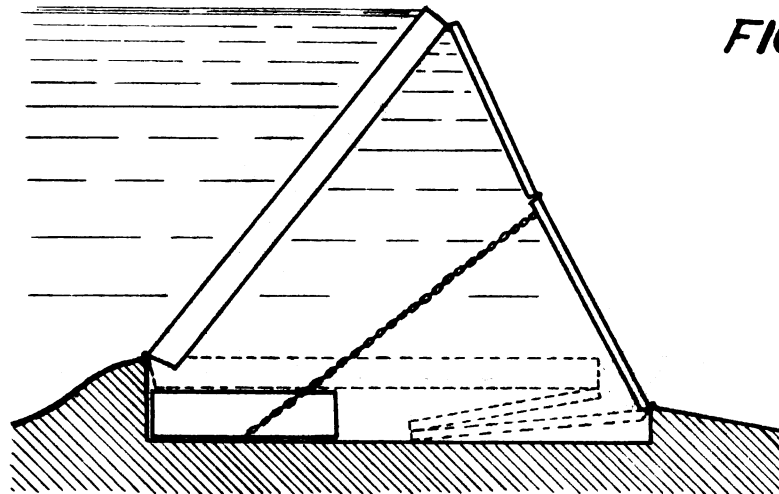
FIG. 6



Vertical Section

CARRO GATE

FIG. 5



Vertical Section

GIRARD GATE

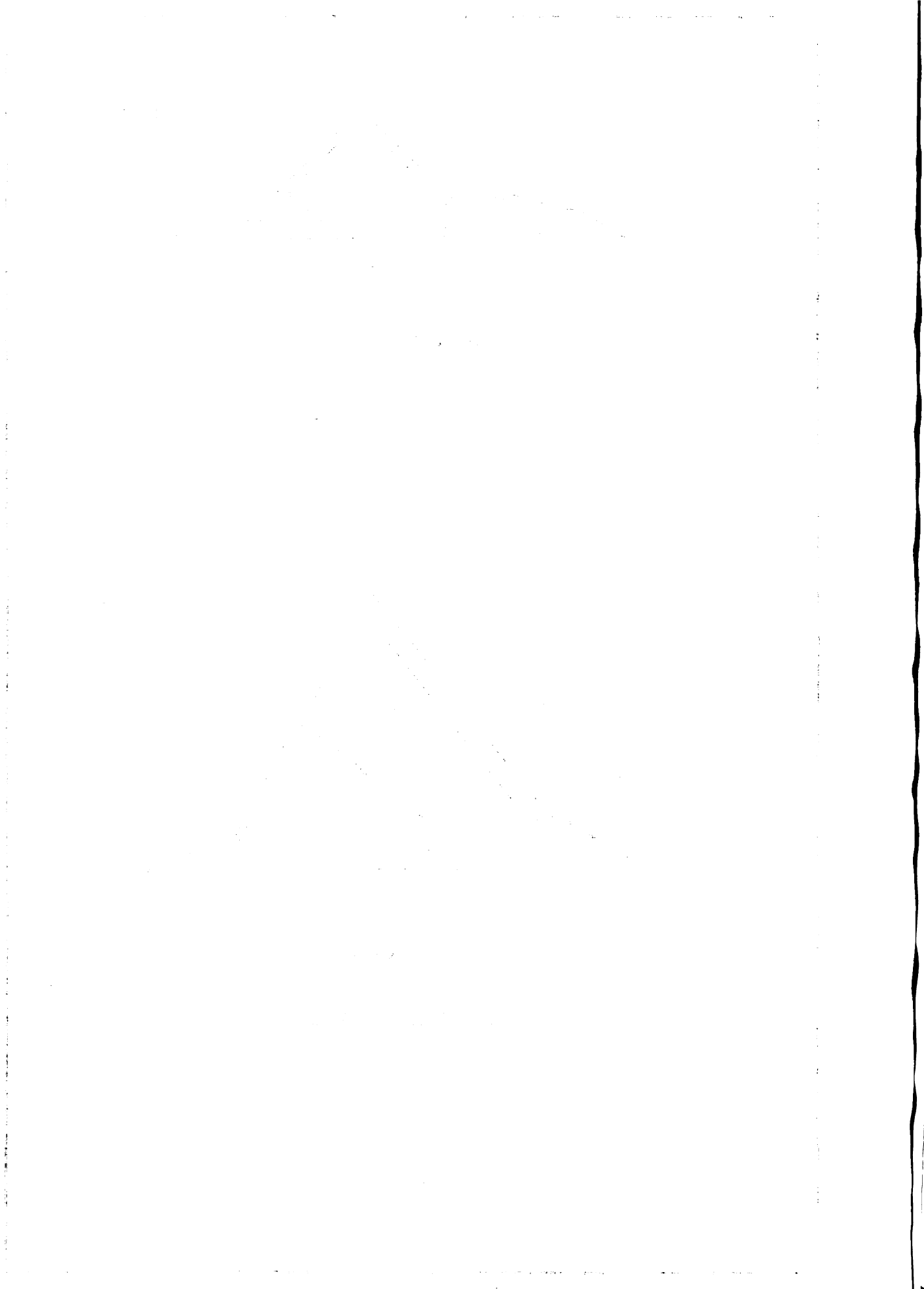
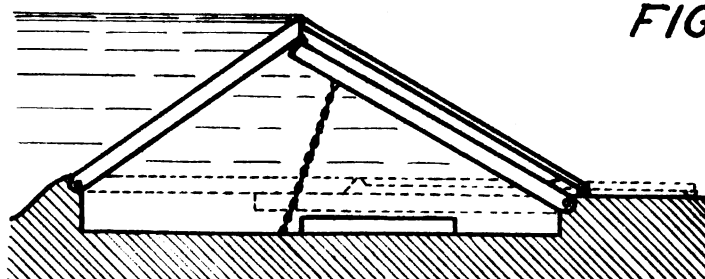


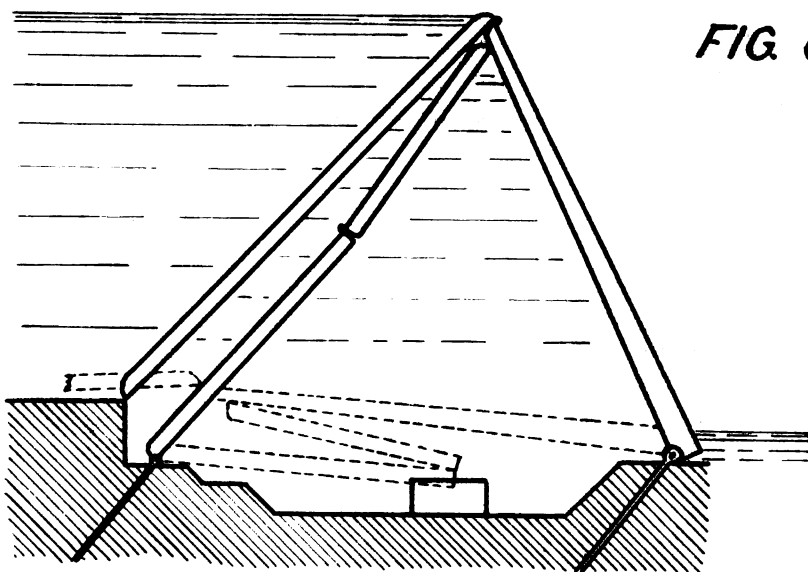
FIG. 7



Vertical Section

DUBOIS GATE WITH APRON

FIG. 8



Vertical Section

PARKER BEAR TRAP GATE



FIGURE 1. A line graph showing the intensity of a signal over time. The curve rises sharply to a peak and then gradually declines.

The following table shows the data points for Figure 1:

Time	Intensity
0	0
1	2.5
2	5.5
3	7.5
4	8.5
5	7.5
6	6.5
7	5.5
8	5.0
9	4.5
10	4.0

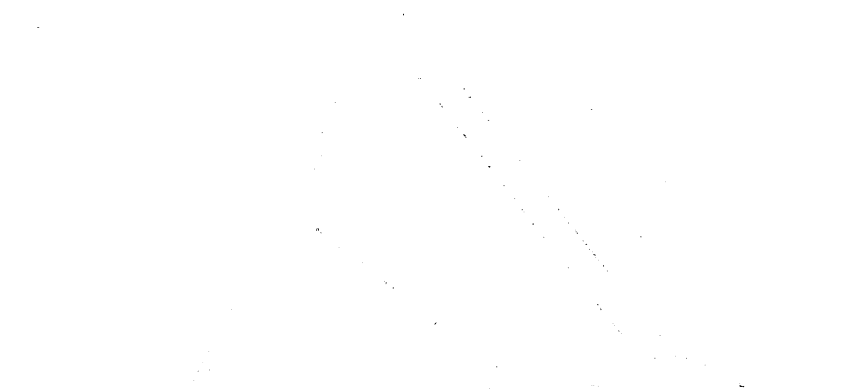
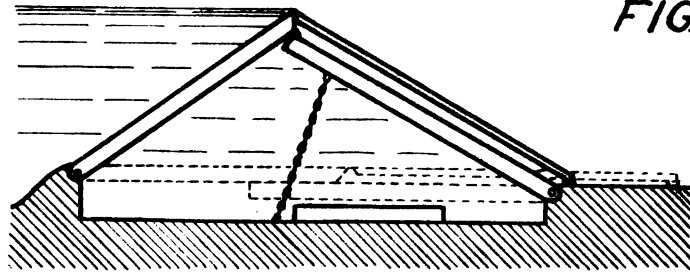


FIGURE 2. A line graph showing the intensity of a signal over time. The curve rises to a peak and then declines.

The following table shows the data points for Figure 2:

Time	Intensity
0	0
1	2.5
2	5.5
3	7.5
4	8.5
5	7.5
6	6.5
7	5.5
8	5.0
9	4.5
10	4.0

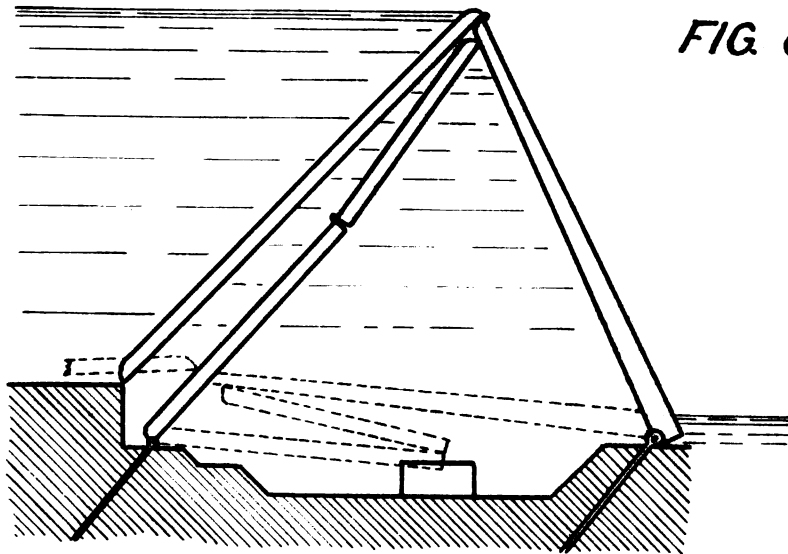
FIG. 7



Vertical Section

Du Bois Gate WITH APRON

FIG. 8



Vertical Section

Parker Bear Trap Gate

makes a lighter gate, but reintroduces sliding friction at the end of the idler. There are two Lang gates in operation at the Geddes plant of the Detroit Edison Co. They operate with perfect ease, responding very readily to the working of the valves. The author was further informed that there is no great difficulty encountered with ice.

According to Mr. Powell, it is hard to say which is the better gate, the Lang or the Parker. The conditions existing at any particular set-up usually determine which is more desirable. There is one small advantage which the Lang gate has over the Parker, and that is that it does not have the condition of unequal water pressures in the chamber at the vertex of the segments of the ~~up~~stream leaf.

By the addition of another set of chains or rods the Lang gate can be made reversible, that is; at a location where the flow of water is one way part of the time and the other way the rest of the time, this gate will serve its purpose for flow in either direction. This condition was encountered at the Sandy Lake Dam. (Ref. 29) The gate functions as a Lang gate in one direction, and when the flow is reversed it functions as an Old Bear Trap. The location of the additional set of chains or rods is shown in Fig. 9 by the dotted line between points 'a' and 'b'.

The Reversed Parker Gate

The Reversed Parker gate, as shown in Fig. 10, is nothing more than a Girard gate with an idler added to it. It therefore has the same qualities as the Girard gate, plus the obvious benefit of the idler. A practical illustration of the use of this gate can be found in Ref. 18.

The Marshall Gates

W.L. Marshall, Major, Corps of Engineers, U.S.A., made several contributions to bear trap gate design. He patented his #1 and #2 gates about 1895. (See Figs. 11 and 12) Compared with the Parker gate, these gates differ essentially in that they fold out from, and not into the chamber. These gates introduce several new problems in forces. The size and the dimensions of the gates can be made such that the forces will do away with the necessity of stay-chains or stops. Mr. Marshall and his assistant discuss the theory of these gates very freely in their report found in Ref. 19.

Referring to the defects of the Old Bear Trap gate, it is found that the two Marshall gates mentioned above

100



Downstream view of the "Lang" bear trap gates at the Geddes Plant of the Detroit Edison Company. Part of an emergency spillway is shown at the right.



Downstream view of single gate showing minute flow trickling over. As can be seen in the picture at the top, very little leakage gets through these gates.



Left: View of downstream valve control wheel at the Geddes Plant. The small motor turns the wheel. A button-switch in the power house controls the motor. The upstream valve wheels are shown in the background. They are for emergency use only as pressure is usually maintained by water entering the chamber between the idler and the upstream leaf.

Below: Downstream view of gates showing valve wheels.

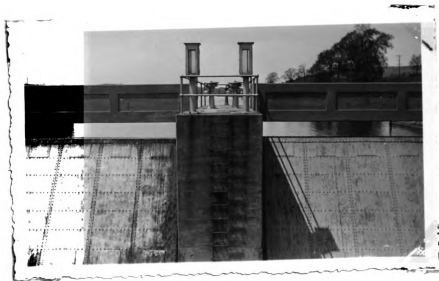
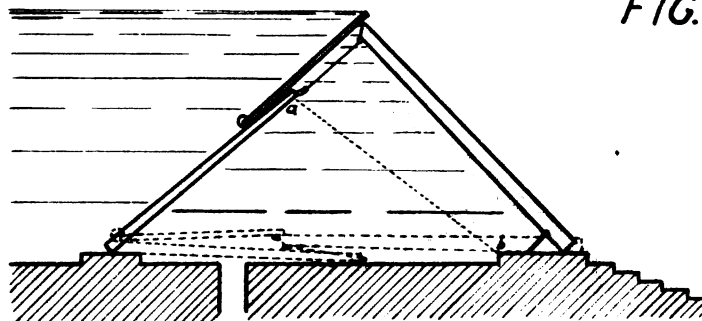


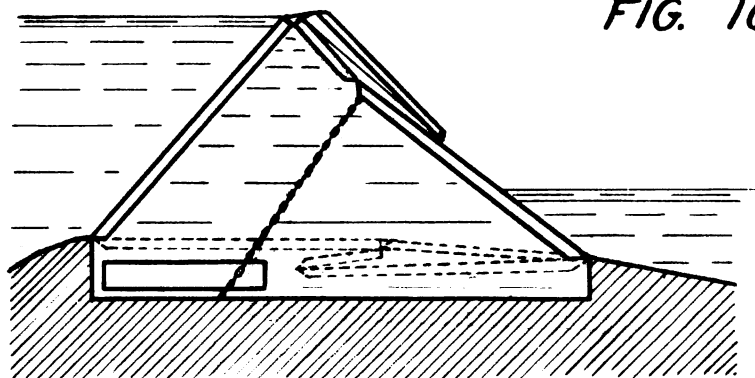
FIG. 9



Vertical Section

LANG BEAR TRAP GATE

FIG. 10



Vertical Section

REVERSED PARKER GATE

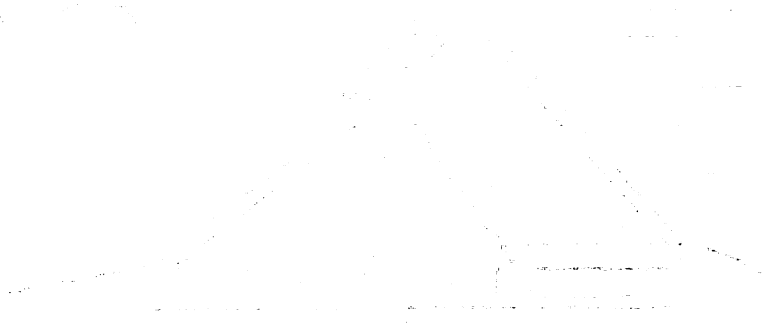
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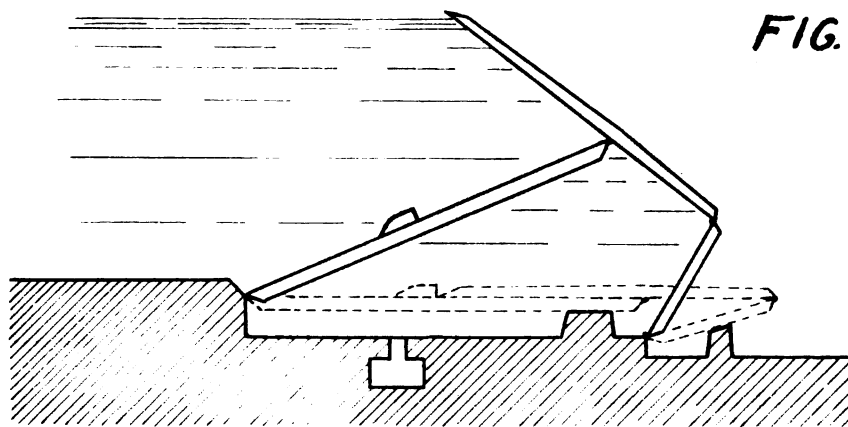
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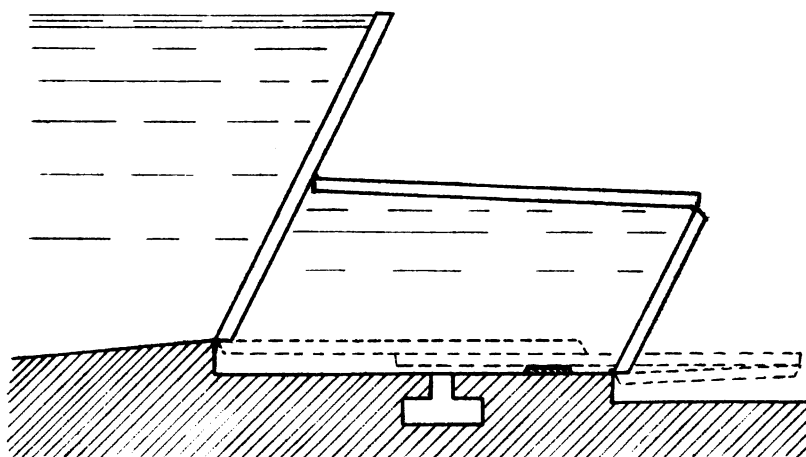
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Vertical Section

MARSHALL'S BEAR TRAP #1

FIG. 12



Vertical Section

MARSHALL'S BEAR TRAP #2

have eliminated (I,II,III,IV,V, and VIII).

A third Marshall gate is shown in Fig. 13. This gate is not fully automatic as it must have auxiliary jets of high head to raise the gate, due to backwater.

The result of an attempt by Mr. Marshall to improve the Old Bear Trap, without too much alteration, is shown in Fig. 14. The special hinged roller device eliminates defects (II and III). The dash-pot like connecting rods eliminate defect (IV). The proper distribution of water by several mains eliminates defect (V). The short idler practically eliminates defects (VI and VII). (See Ref. 16)

The Jones Gate

W.A.Jones, Lieut. Col., Corps of Engineers, U.S.A., shows in Ref. 19 a design for what he terms a "Reversible Weir with Short Base". It is reproduced in Fig. 15 of this paper. It is a series of gates that fold up in a very compact way, thus requiring a very small base, in comparison with other gates, for the amount of head taken care of.

The Jones gate has defect (VII), and lacks simplicity. For conditions that demand a high head and a short base, this gate might be acceptable; but for other conditions some of the simpler gates are best, as simplicity is a key-word in engineering.

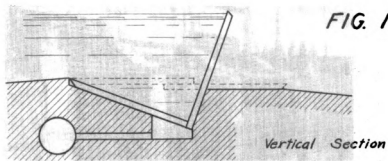
For brief reports on bear trap gates see Refs. 4 and 9.

Tainter, Sector, and Drum Gates

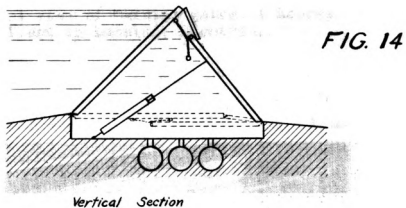
The Tainter gate (a form of sector gate) is a very commonly used gate. It is not an automatic gate, but perhaps could be made so by applying some of the principles that will be developed later in this paper. (See heading "A New Automatic Crest Gate")

The so-called sector gate has its curved face downstream. Fig. 16 shows a set-up for an automatic sector gate. (See Ref. 25) A short explanation with some of the theory of this gate is as follows:

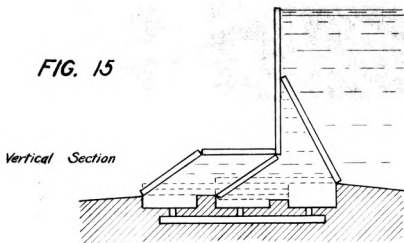
For purely automatic action, the gate valve is closed, the inlet valve adjusted to a desired opening, and the float adjusted to a desired elevation. The gate will then maintain the desired water level automatically, by rising when the siphon is broken and lowering when the siphon is operating. The gate can be operated as a drum gate by an attendant through the use of the inlet and gate valves. In this case they are operated the same as the valves of a bear trap gate.



MARSHALL'S TRIPPING BEAR TRAP



MARSHALL'S MODIFIED GATE



JONES' SHORT BASE GATE



General view of Tainter gates at Moores Park Plant in Lansing, Michigan.



A close-up of one of the above gates. Note the light wood construction, making the gate adaptable to the principle of Part IV of this paper.

The gate is designed to keep its crest above water until fully elevated, providing P_2 is due to the head upstream. Backwater pressures have no affect upon the equilibrium of the gate, as any water pressure on the curved face must act through the axis. The siphon is capable of varving P_2 as much as the equivalent of 6 inches of head in either direction. This variation is sufficient to raise or lower the gate. The caisson (cross-sectioned in Fig. 16) has a drain pipe in it. This may be used to make small variations in the weight of the gate if necessary, by leaving it open or closing it.

The fundamentals of the hydraulic design of this gate are somewhat as follows:

Let S = The leakage from the pit. (+or -)
 Let Y = The water discharged by the siphon.
 Let D = Displacement (The flow in or out of the pit due to the movement of the gate) (+or -)
 Let Q = The water passing the intake. (Subscripts are used for various directions of movement.)

For lowering the gate:

$$Q_1 = S + Y - D$$

For holding the gate down:

$$Q_2 = S + Y$$

For raising the gate:

$$Q_3 = S + D$$

Assuming D is approximately the same in both cases:

$$Y = 2D$$

Therefore: $Q_1 = Q_3$

If the effective head of the siphon is known and its efficiency is between 40 and 50 percent, D can be assumed and Y computed. Therefore for certain assumptions of S , the value of Q_1 or Q_3 can be figured. An operating chart can be made coordinating the adjustment of the two valves with the adjustment of the float. Thereby water can be maintained in the pond at any desired elevation by the corresponding adjustment.

- - - - -

The drum or pontoon gate originated back in the time of the early bear trap gates, in fact the Brunot gate (See Fig. 17) was intended as a bear trap, but developed later into a pontoon gate. (See Fig. 18) Many varieties of the

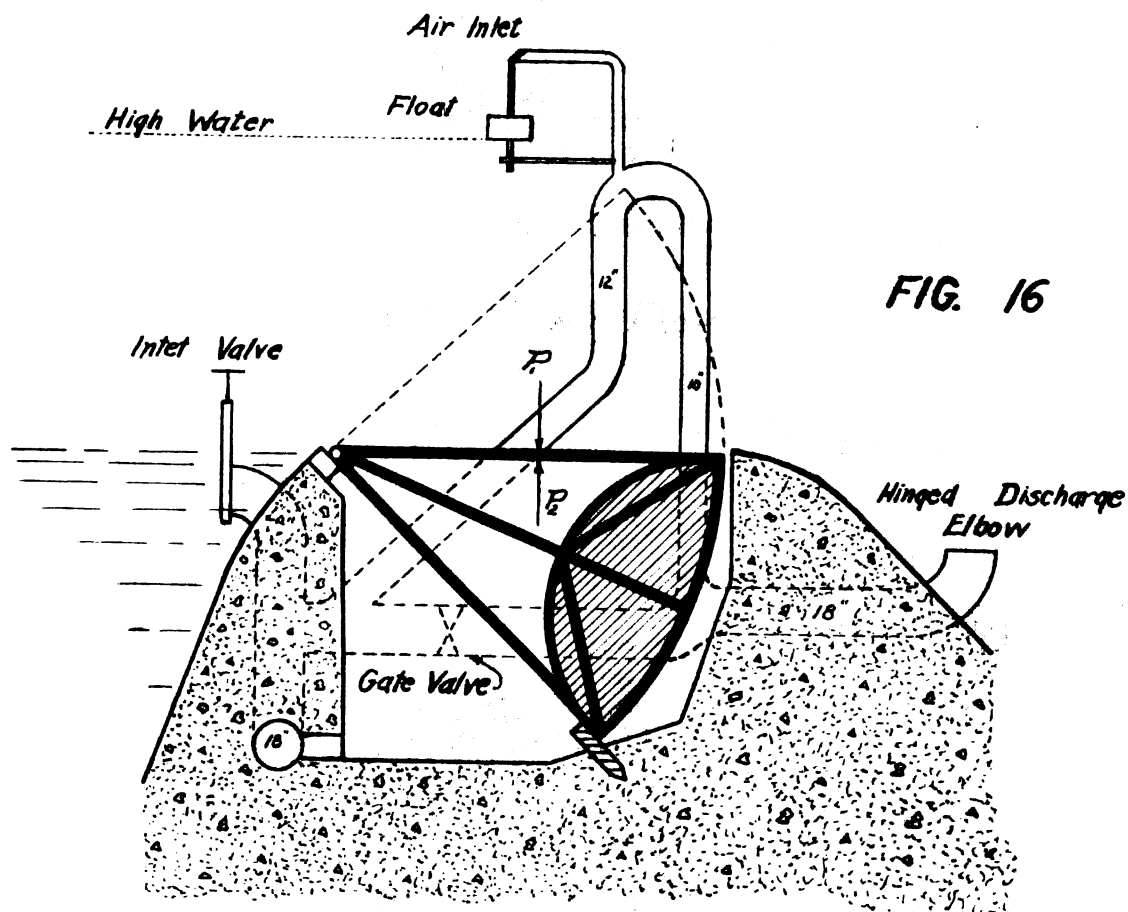
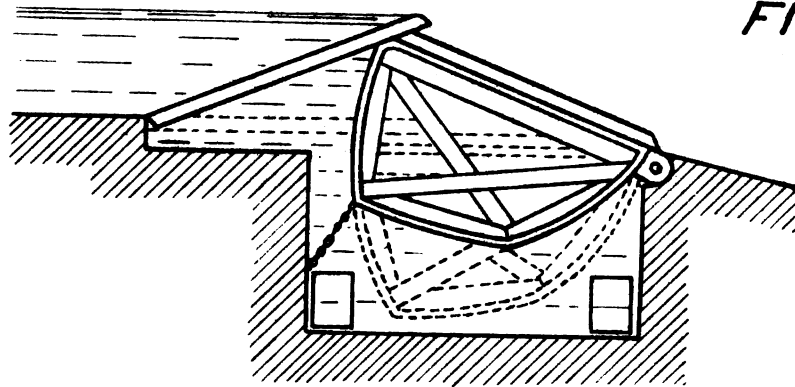


FIG. 16

Vertical Section

AUTOMATIC SECTOR GATE

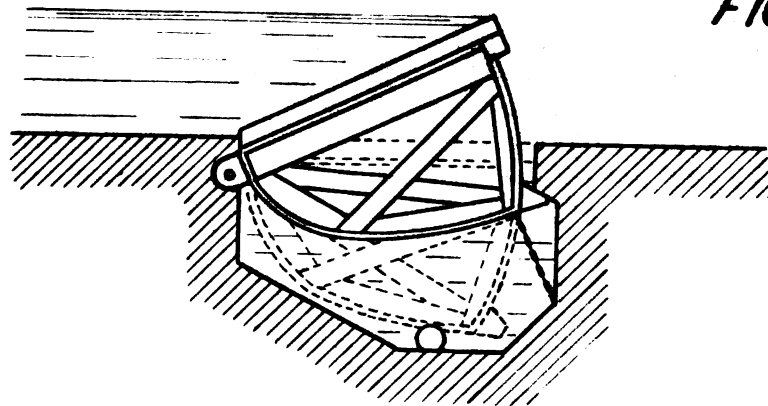
FIG. 17



Vertical Section

BRUNOT BEAR TRAP GATE

FIG. 18



Vertical Section

BRUNOT PONTOON GATE

drum gate have been designed, but they all work in a similar manner to the Brunot gate shown in Fig. 18. The principle of the drum gate is simple. Instead of the lifting force being mostly pressure from the head upstream as in the case of the bear trap gate, it is that pressure plus a buoyant force due to the low specific gravity of the gate. One good feature of the gate is the fact that it is all in one unit, and does not have a lot of separately moving parts.

Flashboards

The flashboard is an auxiliary gate used for obtaining additional head on the dam. It is usually made to break loose or trip if a certain height of water is surpassed. Some of the tripping types of flashboards may be classed as automatic gates.

A flashboard of the type illustrated in Fig. 19 is automatic. It is hinged below the lower third point of the gate; thus the water pressure trips it at a predesigned elevation. The handicap of such a structure is that it leaves too much obstruction in the path of the water and therefore is not good for use on streams containing any debris or having any ice runs. The gate is raised or set up again by an excess of weight in the lower part of the gate, which acts after the high water has subsided.

Better arrangements are the two Swiss gates shown in Figs. 20 and 21. These gates offer less obstruction when they are tripped. Counterweights return the gates after high water has subsided. (For more detailed information on automatic flashboards, see Refs. 17, 23, 24, and 28.)

Rolling Gates

Cylinder Type

The rolling cylinder is used a great deal for gates to be used in wide shallow openings. The cylinder is able to withstand the stresses of wide spans without being too heavy a structure. It is easily heated for ice conditions as it is an inclosed affair. The rolling principle also makes the gate lighter to lift, as a component of the weight is supported by the inclined rack. J.E. Jenkins of New York, patented an automatic roller gate, but the author has been unsuccessful in obtaining a description of it.

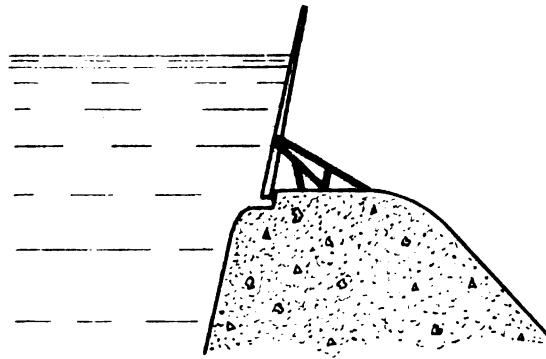


FIG. 19

Vertical Section

TRIPPING FLASHBOARD

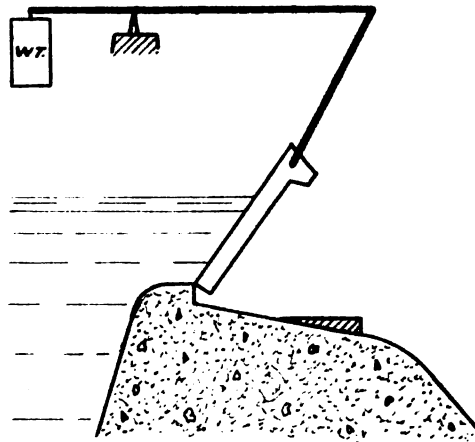


FIG. 20

Vertical Section

OVERHEAD COUNTERWEIGHT, FLASHBOARD

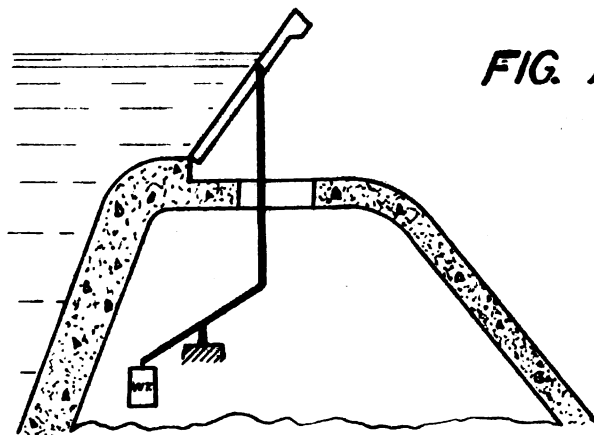


FIG. 21

Vertical Section

HIDDEN COUNTERWEIGHT, FLASHBOARD

Shutter Type

A modification of the rolling cylinder is the rolling sector or shutter. This gate is used where a complete cylinder would be too large to handle or require too much material to build.

Siphon Spillways

The siphon spillway is a purely automatic device for maintaining the desired water level on a pond. If properly designed and constructed it will operate with very small variations in the water level. It has practical limitations however, such as the use of a suction head of no greater than 25 feet (34 feet theoretically). Its construction is rather expensive due to the form work necessary. It is not the best sort of a device for the colder climates, as it quite readily clogs with ice, and therefore requires more equipment for the prevention of such clogging. The siphon spillway gives an increased discharge over that of the ordinary spillway or weir. It is a very effective device if used in plants where the conditions make it readily adaptable. (For an illustrative description of a modern set-up, see Ref. 27.)

PART II

Ice, Ice Troubles, and Remedies

Introduction

In treating this subject, it will be divided into two parts: First, a short explanation of the various forms of ice and the difficulties they present. Second, some of the remedies used at the present time in engineering practice.

A thorough analysis of ice and ice conditions is out of the question in such a short paper, especially when this subject is only a part of the intent of the paper. However the high points will be touched upon, and the conditions affecting gates will be discussed in more detail.

H. F. Barnes, Associate Professor of Physics, at McGill University, Montreal, has spent a great deal of time in study and in research work on ice. His results are very helpful to the engineer contending with ice conditions, and may be found in his text and other writings. (Refs. 14 and 15)

The four principle types of ice that the power plant engineer must deal with are; frazil ice, anchor ice, sheet ice, and frozen leakage.

Ice and Ice Troubles

Sheet Ice

Sheet ice occurs on the surfaces of the bodies of water. As the weather grows colder, the cold surface waters sink and the warmer waters rise. This process reaches a limit when all the water has neared the freezing point. As more heat radiates from the surface, the surface freezes into a sheet. This sheet becomes thicker as the heat continues to radiate from the water. Sheet ice is found mostly in quiet waters such as ponds, lakes, and the slower streams. It usually ranges from a few inches to 3 or 4 feet in thickness.

Sheet ice is easier to handle than anchor or frazil ice as it is on the surface and is not so difficult to get at. Sheet ice is often desirable, as it prevents the formation of the other types. The sheet tends to quiet the waters which along with the heat of friction under the sheet prevents the frazil and anchor ice from forming. If the conditions are very severe, any additional ice forming will do so in the way of thickening the existing sheet of ice.

The main difficulties encountered with sheet ice are,

the pressure exerted against the gate, and the ice break-up in the spring. The pressure is usually the greatest source of difficulty, and has been known to break gates in several instances. The spring break-ups causing damage, where the ice runs out of the ponds, are only found in the more flashy streams. Ordinary conditions are such that the ice melts or rots in the ponds for the most part.

Frazil Ice

Frazil ice occurs in rapidly moving or violently agitated waters. It has needle-like crystals and is a slushy formation. These crystals, according to Mr. E.M. Burd of the Consumers Power Co. of Michigan, are "ready to seize upon and matt over any object in the current where it may slow down." Frazil ice has been known to be as much as 20 or 30 feet deep or thick; sometimes completely filling portions of the pond or stream. (See Ref. 14)

Frazil ice presents one of the greatest difficulties for winter operation. It masses behind the dam and gates and thoroughly clogs any moving parts by adhering to them or wedging in them. In severe cases it prevents operation for a period of time until the ice can be removed, thereby endangering the plant, the dam, and any property or lives below the dam, should high water come on suddenly.

Anchor Ice

Anchor ice, as its name indicates, is found at the bottom of bodies of water. It forms about objects which have become chilled, such as stones, metal, or concrete. This formation differs from frazil ice found submerged, in that it is very hard.

Anchor ice is thought by some to be more troublesome after it has broken loose and floated to the surface, but in general this is not true. When on the surface it can be treated like broken sheet ice, but when submerged it presents difficulties of an entirely different character. It forms about the submerged parts, especially the metal ones, and prevents their movement. Being very hard, it takes more heat to melt than frazil. It is anchor ice that forms what is known as the "ice-gate" in the very cold climates. (Ref. 11) A thick layer of ice forms behind the structural gate over its whole depth. After the actual gate has been broken free and raised, the ice gate remains making it impossible for the water to pass through. This ice gate has been known to remain for several hours before giving way.

Frozen Leakage

Considerable difficulty is encountered with gates freezing tight. This phenomena is often caused by the freezing of leakage about such parts as guides, hinges, and movable parts or joints. According to Mr. Burd, it is almost impossible to seal the gates so tight that there is no leakage whatever. "There is always some small leakage, and in the course of several months of freezing weather this accumulates so much ice on the gates and so effectively freezes them in position that to lift them is impossible without removing at least a part of the ice and doing something to break the seal."

Remedies for Ice Troubles

Explosives

The use of dynamite or explosives in fighting ice conditions is often necessary in sheet ice jams or in excessive formations of frazil ice. Mr. Barnes has experimented a great deal with the use of "thermit" in the place of ordinary explosives. His results can be summarized as follows: (See Refs. 12 and 20)

Thermit is the trade name for an exothermo mixture of aluminum metal and iron oxide that is used ordinarily for welding. It attains a temperature of from 2500 to 3500 degrees centigrade a few seconds after ignition, but only has a heat content of around 1500 B.t.u. per pound. Although the heat content is low, thermit is very effective due to its extremely high temperature.

Once ignited, the molten iron decomposes the ice (H_2O). The iron unites with the oxygen, liberating the hydrogen which burns in the free air causing a slow explosion which helps to further break the jam.

The explosion mentioned is the slowest explosion known to Mr. Barnes. It is so slow that it is not injurious to structures in immediate contact, and it will not harm the fish in the pond or stream.

Heaters and Blowers

One method of fighting ice at the gate proper is the installing of an electric or a steam heater, supplemented by an air blower, in the gate. Unless the gate is housed in, this method is not economical as large quantities of heat

are lost. This method is quite applicable to Tainter, roller, and sector gates. It seems as if it might be used successfully in drum or pontoon gates, if not already tried. If a steam heater is used, it is usually supplied from the power house heating unit, and does not require any special unit of its own. The following are some remarks taken from a report of the National Electric Light Association. (See Ref. 13)

1. This method works well alone.
2. This method can be operated (electrically) with 16.5 watts per sq. ft. of gate area, and maintain a temperature of better than 32 degrees fahrenheit.
3. Air circulation is essential for the economic use of the heat.
4. The gate must be housed in if not of a hollow type for the economic use of the heat.
5. Where there is a series of gates, only the end gates and possibly a center gate need be heated, as the currents caused by these gates being open, will soon have the other gates operable. (This statement applies to all heating systems.)

Heat Filaments and Heat Lines

The installation of electric heating filaments or steam lines in the embedded parts, such as guides or seats, is often a very effective method of combating ice hazards. This method is used where comparatively thin gates, such as sliding gates, are found. It is also applicable to bear trap gates, by installing the electric coils or steam tubes just under steel plates in the sides of the piers along the lines that the gate edges assume in the most frequented winter position. (This is usually with the gate fully raised.) The coils or tubes are also very effective when installed in, or near the upstream and downstream base hinges, especially the downstream hinges. The use of electricity or steam as above described is very effective in preventing the leakage from freezing on strategic parts. (Ref. 11)

Compressed Air

The use of compressed air to prevent ice from forming on the face of the gate is quite successful. The following, concerning the same, has been stated by Mr. Burd: "A very slight current of compressed air next to the bottom of a gate, of merely sufficient pressure to cause it to escape

will set up sufficient circulation of the water so that very little ice forms on the face of the gate. This is quite an economical and effective method, and has been used extensively on the St. Joseph River and on the Menominee River. Both the equipment required and the cost of operation are very moderate. This plan does not, however, keep ice from forming on the downstream face of the gate due to leakage past the seal."

In the report in Ref. 11, there is mentioned the practice of electrically heating the air before it is bubbled out into the water. In a summary given in Ref. 22, a method of using heated air from the generators is described. Also an A.S.C.E. report, found in Ref. 10, contains information on the use of warm compressed air for preventing ice-thrust. (Ref. 10 contains quite an extensive bibliography on ice conditions.)

The N.E.L.A. report (Ref. 13) advises against the use of the compressed air system by itself, except in rare instances. They find that it is not sufficient to meet the situation except as an auxiliary unit to some other heating system.

Ice Prevention by Orientation

The following is from a letter from Mr. Burd: "It makes a good deal of difference which way the gates face; that is, if the pond is on the northerly side of the gates then the gates get the full south sun and this helps in keeping them free from ice. Thus, the orientation of the dam warrents careful thought if it is to have an exposed gated spillway." This is a good point to keep in mind if designing a power project, in a climate where ice must be contended with. Often in the preliminary survey several prospective locations are considered, and eliminated one by one until the best remains. If the stream is a winding one, the direction of the sun plays an important part in the elimination of possible sites.

Undersluices

The proper use of the undersluice is advantageous to a plant confronting ice conditions. If the inlet is well under the surface, it will not be subject to ice unless an extreme case of frazil is encountered. There are two reasons, usually, why a system of undersluices should not be built to do away with all the other gates. First, is the high cost of the concrete form work; second, is the fact that such a system would require a very elaborate arrangement of floats and undergates to keep the water at a constant level. How-

ever, the undersluice works well as a means of passing an ordinary amount of water while the gates are being freed from ice. This is a safeguard against a washout when high water unexpectedly catches a plant with frozen gates.

The Use of Chemicals

Often a slight change in temperature can reverse conditions; that is, can destroy the ice just enough to make the gates operable. This is especially true with frazil ice. However, instead of raising the temperature by one of the aforesaid heating systems, it is found quite convenient, sometimes, to lower the freezing point. This is done by distributing certain chemicals over the ice around the gates. The following have been found to work quite satisfactorily in rotting the ice: sodium chloride, calcium chloride, calcium carbide, crude sulphuric acid, and crude hydrochloric acid. These chemicals can be used to a still better advantage if mixed with sand or gravel before applying. This will draw the heat from the sun's rays. (See Ref. 20)

Chopping Out and "Cracking"

In many cases it is impossible to spend money on heating equipment, especially if the plant is a small one. If labor is cheap and easily available, the gates can be kept chopped out. In severe weather chopping is necessary in a small amount at plants having heating systems.

A method of avoiding much of this undesirable labor is known as "cracking" the gate. The gate is opened a small amount and cracked free whenever the ice begins to get a hold on it. In severe weather this has to be done as often as once a day. The gates best adapted to such procedure are the automatic gates as they require no expense or labor to operate. Thus, the automatic gate, especially the bear trap, fights its own ice conditions and is kept free to operate without a lot of auxiliary heating equipment.

PART III

Conclusion

In this conclusion, the ice conditions and the methods of combating ice difficulties will be classified, and a chart will be presented. This chart is for the purpose of helping the designing engineer make his choice of a gate, from the standpoint of added cost involved in overcoming ice difficulties.

Conditions

As stated before, the condition of leakage is always present. It may be cut down considerable by the proper use of such devices as felt or rubber seal strips, rubber compound in the hinges, or the "staunching rod." (Ref. 24)

Thus, the possible ice conditions may be divided into two classes, both containing leakage. They are as follows:

- I. The open forebay, including;
 - Leakage
 - Frazil ice
 - Anchor ice
- II. The closed forebay, including;
 - Leakage
 - Sheet ice

Combat Methods

In the preceding part of this paper, 8 specific methods of combating ice were presented. They will be listed below for the convenience of referring to them, and for expense comparisons. A ninth item will be added to the list for reasons to appear later.

The expense that is under consideration is the added expense of fighting the ice, and not the initial expense of the gate and foundations. This added expense is of two types, initial installation cost of extra equipment, and operation cost of this equipment or any destructible materials.

- 1. Use of explosives (Has operating expense)
- 2. Heaters and blowers (Has initial expense and operating expense)
- 3. Heat filaments and heat lines (Has initial expense and operating expense)

4. Compressed air (Has initial expense and operating expense)
5. Orientation of dam (May or may not cause extra expense)
6. Undersluices (Has initial expense, and possible operating expense if power driven undergates must be operated)
7. Chemicals (Has operating expense)
8. Cracking (Has operating expense for non-automatic gates, but NO EXPENSE for AUTOMATIC GATES)
9. Extra equipment to prevent formation of ice in valves, channels, and chambers (Has initial expense and operating expense)

Chart

GATES	CONDITIONS			
	OPEN FOREBAY		CLOSED FOREBAY	
	Leakage	Frazil & Anchor	Leakage	Sheet
Non-automatic sliding gates	3	1 or 4	3	4
Automatic sliding gates	8	1 & 9	8	8
Bear trap gates	8	1 & 9	8	8
Non-automatic Tainter, sector, and drum gates	3	1 or 2	3	2
Automatic sector and drum gates	8	1 & 9	8	8
Rolling gates	2 or 3	1 or 2 or 4	2 or 3	2

The purpose of the chart on the preceding page is not to point out which is the best gate to use. It is to be used as an aid in choosing a gate for a given project, giving due consideration to the added expense caused by the provisions necessary for overcoming ice hazards. The numbers refer to the list of methods on pages 20 and 21. The gates used in the chart do not make a complete list, but are some of the most common types from the ice standpoint. The methods indicated for the various gates and conditions are suggested as to what might be the best under the circumstances. There may be exceptions where the suggested methods will not hold.

Comments

From the inspection of the chart, it can be concluded that in general automatic gates are best for closed forebays and non-automatic gates are best for open forebays. This is only so far as ice costs are concerned. There may be other costs, such as the cost of the gate proper or the foundation, that would make it advisable to use a gate of higher ice expense.

The orientation of the dam (method 5) may make it possible to operate without extra methods for combating leakage. If the climate is not too severe and this is so, the arrangement as given in the chart will be some different. This should be considered when choosing the gate.

Undersluices (method 6) can be considered as a precaution to be used with any gate for the more severe conditions. It therefore does not effect the choice of the gate very much. It should be considered, however, before the final choice of the gate is made.

The use of chemicals (method 7) does not effect the choice of the gate very much, but may be used to advantage in many situations with practically any gate.

It is well to keep in mind that a combination of gates might be the solution to the ice problem at some particular location. It has been practice in some of the Michigan plants to use a group of several Tainter gates. One or two of the end Tainters would then be housed in and heated. This of course is added expense, and it might be feasible when designing a project to install an automatic gate in place of an end Tainter. This principle might be applied to other situations. (The credit for this suggestion should go to Mr. Burd.)

PART IV

A New Automatic Crest Gate

Operation and Discussion

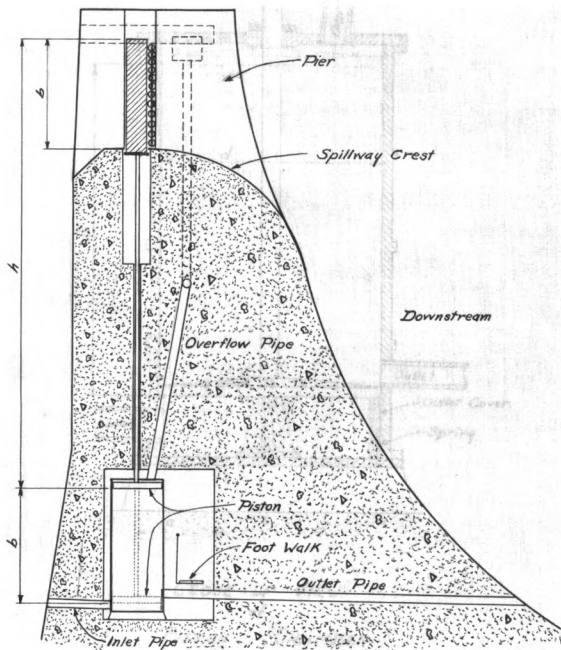
The purpose of presenting the following few pages of discussion on a New Automatic Crest Gate is mainly to illustrate a principle of automatic gating. For this reason the drawings are not detailed and contain just the necessary features to aid the discussion in illustrating the previously mentioned principle. The theory given is by no means complete, although it does give some idea of what forces must be considered in the design of such a gate.

The gate as shown in Fig. 22, is a purely automatic gate. It should operate entirely under its own power if properly installed and regulated.

The water in the upstream pond is always in contact with the underside of the piston. It is intended that the piston be of such a size that, when the pond level is at or above the spillway crest, the pressure on the underside of the piston will raise the gate. The gate will then remain up until the pond level exceeds a predetermined elevation. This elevation is determined by adjusting an overflow box in the pair. When the water overflows into this box it exerts a pressure on the upperside of the piston by the way of an overflow pipe. This added downward force causes the gate to lower. The piston, on its downward journey opens the outlet cover. (Fig. 23) The outlet pipe is smaller than the overflow pipe, therefore as long as there is overflow the gate will remain down and allow water to go over the spillway. When the pond has subsided again to the desired elevation, the overflow will cease. The weight of the water flowing over the crest will hold the gate down until most of the water above the piston leaves the chamber through the outlet pipe. At a certain predesigned point the upward water pressure will again dominate and the gate will rise. It will rise all the way, despite the small amount of water remaining in the overflow pipe, because as it goes up the weight of water flowing over the top of the gate decreases, thus lessening the total of the downward forces. (When the piston goes up the outlet cover springs over the outlet, thus preventing the water under the piston from leaving the chamber.)

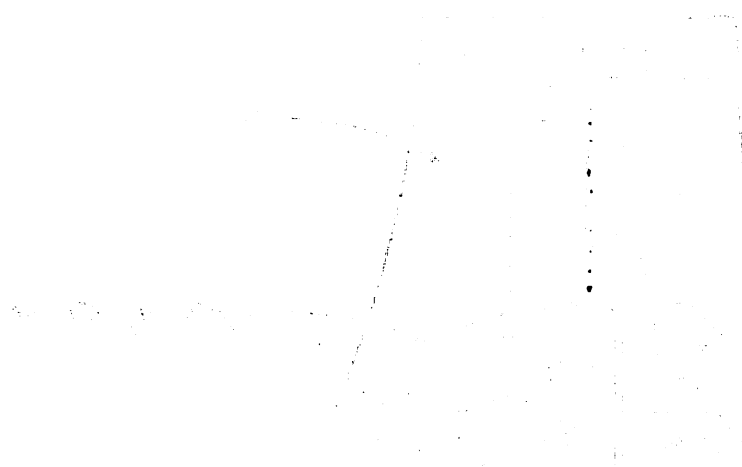
The tendency of the gate is to keep the pond at a desired elevation, which is usually at a point on the same level with the top of the gate when it is up.

FIG. 22



SECTION THROUGH SPILLWAY OF
NEW AUTOMATIC CREST GATE

1000000



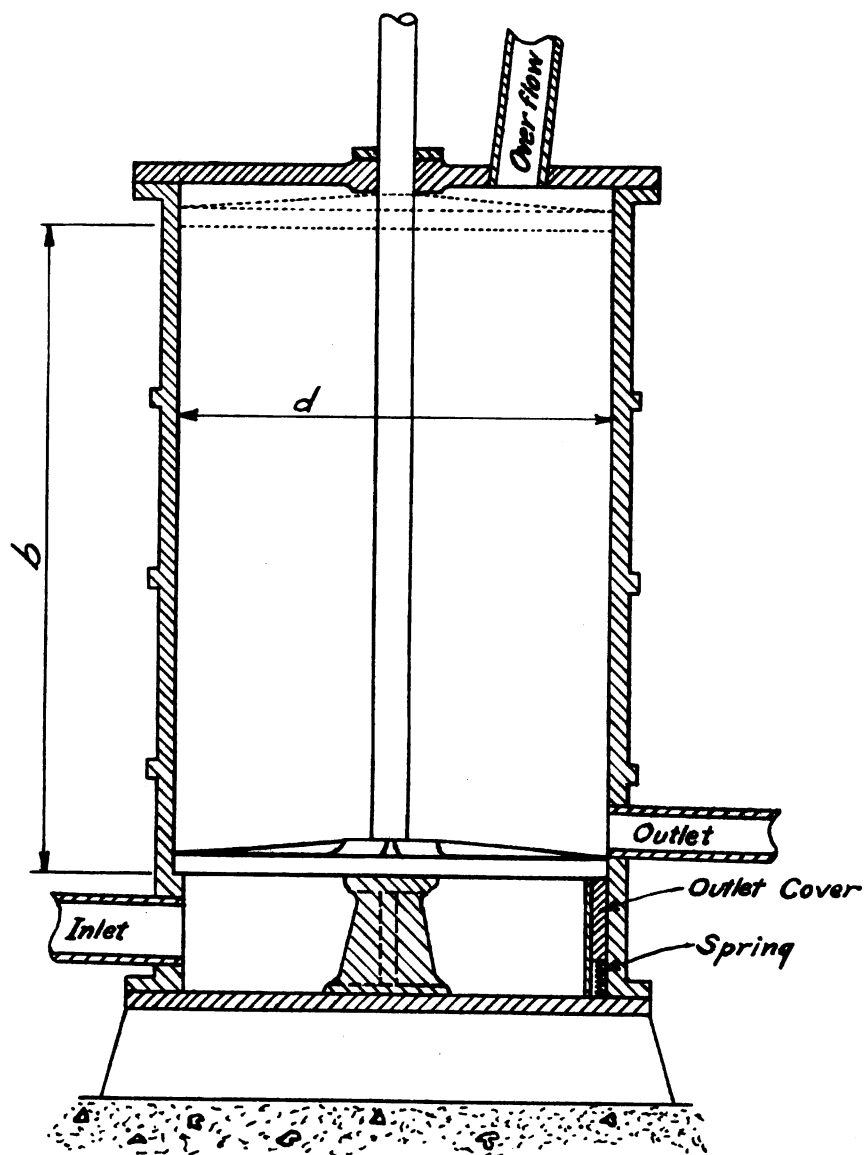
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1000000



FIG. 23



CLOSE-UP VIEW
of
PISTON CHAMBER

Theory

Key to Symbols

W = Weight of gate, piston, and rod in lbs.
 w_g = Weight of gate in lbs.
 A = Area of gate in sq. ft.
 w_r = Weight of rod in lbs.
 w_p = Weight of piston in lbs.
 F = Friction of gate, piston, and rod in lbs.
 f = Friction of gate due to water pressure in lbs.
 U = Upward water pressure on piston in lbs.
 d = Diameter of piston in ft.
 h = Head on piston when up in ft.
 b = Distance gate moves in ft.
 a = Weight of cu. ft. of water in lbs.
 T = Downward force due to spill-water in lbs.
 D = Downward water pressure on piston in lbs.
 h_1 = Head loss in either pipe in ft.
 r_r = Radius of piston rod in ft.

Condition of Raising Gate

The minimum U (U_{min}) which must raise the gate is when the pond level is even with the spillway crest. The greatest U (U_{max}) is when the pond level is even with the top edge of the overflow box. The latter condition is the one to design for as the downward forces to be overcome are greater due to the weight of the water flowing over the gate.

Therefore the condition necessary to enable the gate to rise when the pond is at the desired level is:

$$\textcircled{1} \quad U_{max} > W + F_{max} + f_{max} + T_{max} + h_1$$

Condition of Keeping Gate Up

When the gate is held at raised position, the only downward force is W , and the only upward force may be as small as $U_{min} - \frac{\pi d^2 b a}{4}$

$$\text{Therefore:} \quad U_{min} > W + \frac{\pi d^2 b a}{4}$$

$$\textcircled{2} \quad \text{Or:} \quad U_{max} > W + \frac{\pi d^2 b a}{2}$$

Condition of Lowering Gate

When water begins to overflow, the force W is aided by the new force D and the gate lowers. The opposing upward forces are U, F, f , and h_1 . The condition for lowering is therefore:

$$W + D_{\min} > U_{\min} + F_{\max} + f_{\max} + h_1$$

- ③ Or: $W + D_{\max} > U_{\max} + F_{\max} + f_{\max} + h_1$
(Individual forces will be explained later.)

Condition of Keeping Gate Down

The forces tending to keep the gate down are W, D , and T . The only upward force is U . Therefore the condition is:

$$W + D_{\max} + T_{\max} > U_{\max}$$

- ④ Or: $D_{\max} > U_{\max} - W - T_{\max}$

Summary of Conditions

In order to have a gate which will operate in the right way, the four conditions of expressions 1, 2, 3, and 4 must be satisfied. It is obvious that a value of $U_{\max}$, large enough to satisfy expression 1, will be large enough for expression 2. Likewise the value of $D_{\max}$ must be found from expression 3 in order to satisfy both expression 3 and expression 4.

The upper area of the piston is smaller than the under area because of the piston rod. Therefore:

$$U_{\max} = D_{\max} + \pi r_r^2 (h + b) a$$

Substituting for $U_{\max}$ in expression 3:

$$W + D_{\max} > D_{\max} + \pi r_r^2 (h + b) a + F_{\max} + f_{\max} + h_1$$

Therefore:

- ⑤ $W > F_{\max} + f_{\max} + h_1 + \pi r_r^2 (h + b) a$

This condition will obviously be so unless the gate

is counterweighted. Therefore, if the value of U_{max} satisfies expression 1, all four expressions will be satisfied. (Expression 5 sets a very definite limit on the use of the counterweight.)

In order to evaluate U_{max} , each of the terms on the right must be determined. Apparently this is not too simple a matter and requires much of the design detailing. Therefore the terms will only be discussed briefly in this paper.

The Weight (W)

The weight of the gate depends on the type of gate used. This weight can be accurately figured when the gate is detailed. For a rough estimate, the formula for Stoney gates given in Ref. 21 may be converted to the english system giving the weight in lbs.

$$w_g = 24.2A + .0448A^2$$

The weight of the rod is easy to determine when the length is known and the approximate load on it has been found. An empirical formula would perhaps be some constant times some power of the length:

$$w_r = k(h + b)^x$$

The weight of the piston will perhaps have to be assumed, as the diameter of the piston is still unknown. This weight varies as a constant times some power of the piston diameter:

$$w_p = kd^x$$

The total of the downward weights is:

$$W = w_g + w_r + w_p$$

The Friction (F)

This friction is due to the piston rings, the rod guides, and the gate seals. It cannot be figured very closely until the design has been detailed. If assumed, it should not be more than a few hundredths of W, as the frictional forces are parallel to the weights. Careful design and construction should practically eliminate this force. (F)

The Friction (f)

This friction is due to the pressure of the water against the gate. It varies with the amount of gate area exposed to the water. With a Stoney type gate having a roller train, it should not exceed:

$$f = .01W$$

Water Over the Gate (T)

This force varies from zero to one of considerable magnitude. It is quite important in operating the gate. It is greatest when the gate is down and the water has just ceased overflowing into the overflow pipe. T is equal to the weight of the water directly over the gate, therefore the thickness of the gate is quite important. Obviously, T cannot be determined until the length, thickness, and rise of the gate are known.

The Head Loss (h_l)

The head loss of a pipe varies with the square of the velocity. The velocity need not be very high to operate this gate, therefore the loss should be very small. With a good choice of pipe sizes, the loss should be less than .02ft., and therefore could be neglected in the design of the piston.

The Upward Water Pressure (U)

This pressure is due to the hydro-static head of the pond. It is a maximum when the gate is down and decreases as the gate is elevated. A little study of Fig. 22 will bear this fact out. The formulas for U_{max} and U_{min} are:

$$U_{max} = \frac{\pi d^2(h+b)a}{4}$$

$$U_{min} = \frac{\pi a^2 h a}{4}$$

All the values except "d" can be determined along with the terms on the right side of expression 1. Therefore "d" can be solved for.

Remarks on the New Automatic Gate

At many installations of automatic crest gates of the Stickney type, the available head is greater than that used to operate the gate. This requires a very large surface to apply the pressure to. In the new gate just presented, this area is reduced considerably by the use of a long rod and a piston which make use of most of the available head. Therefore for high head (30 to 100ft.) developments, the new gate should be economical as the piston would not have to be so very large.

The new gate as shown, should work quite well in a dam such as the Calderwood Dam. (Ref. 1) It should not cost more and perhaps not as much as it eliminates two gantry cranes and their accessories. The present set-up at the Calderwood Dam requires two or three hours to open or close all the gates, and uses considerable power to run the cranes. This new set-up would make it possible to open or close all the gates in a few minutes, and would require no power other than that furnished by the water itself.

The new gate as shown in Fig. 22 would not be very economical for very low heads. (30 ft. or less) The reason is that it would require too large a piston. However, if an arrangement of counterweights is added, the size of the piston would be greatly decreased, and the gate will have a more practical aspect for low heads. This addition of counterweights requires quite a little study to determine just what they should weigh. (See expression 5)

The additional expense for form work required for the New Automatic Crest Gate should not be very great. The work consists of a rectangular tunnel, some gate pits, and channels in the piers. The pipe can be laid with the concrete. Of course the strength of the dam must be considered before designing such openings in it. For this reason the whole idea might work out better in a hollow dam.

Comparing the cost of the new gate with other gates, both automatic and non-automatic, would be quite an undertaking, and is out of the question in this paper. The new gate, however, can be placed in the class of the other automatic gates, and is therefore advantageous for ice operation due to its ability to "crack." (Auxiliary valves on the ~~inlet~~ inlet and outlet pipes would make the gate operable in a similar manner to the bear trap gates.)

It may be possible to adapt the principle of the "piston" to the modern Tainter gate. A simple sliding connection of some sort would be necessary to permit the rod to move vertically while the gate swings in its arc. The overflow pipe and mechanism could be abolished if desired, and the gate operated by the previously mentioned auxiliary valves.

Thus, if the principle of the "piston" is workable, it will make possible an automatic Tainter gate. By the use of the auxiliary valves, a minimum amount of added equipment is necessary. This added equipment may not cost any more than enclosing a Tainter gate and installing a heating device. With such an automatic gate the advantages of a Tainter gate may be had, ice may be overcome by the costless operation of "cracking," and power or labor will be saved in operating the gate.

THE END

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