The Distribution of Water in Reservoirs by Means of Orifices
THE DISTRIBUTION
OF
WATER IN RESERVOIRS
BY MEANS OF ORIFICES

BY

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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE
IN
MUNICIPAL AND SANITARY ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1906
UNIVERSITY OF ILLINOIS

June 1, 1906

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED THE DISTRIBUTION OF WATER IN RESERVOIRS BY MEANS

OF ORIFICES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Municipal and Sanitary Engineering

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HEAD OF DEPARTMENT OF Municipal and Sanitary Engineering
The Distribution of Water in Reservoirs by Means of Orifices

I. Introduction.

Settling basins for the sedimentation of water, of the continuous flow type, are similar to softening tanks in that the water or sewage flows in at one point, undergoes a change or process while in the containing vessel, and finally flows out at another point. It is evident that any portion of the settling basin or tank which in no way has an effect upon the process involved is a useless adjunct; worse than useless, as it is an item of expense in construction and maintenance, often in an amount beyond the ordinary conception. Any portion of a tank through which no flow occurs is useless. Besides, the efficient operation of such a tank requires a uniform velocity throughout.
Hence it will be seen that it is of primary importance to make every feature useful and to secure a uniform distribution of the flow throughout the entire cross-section of the tank.

An important element in accomplishing this lies in the design and arrangement of the woman of entrance and exit of the water or sewage in a basin of this nature. Consider a settling basin built at a cost of $100,000. It is not hard to imagine conditions to be such that the flow occurs through a portion consisting of two-thirds of the cross-section. In this case $33,000 would represent the amount invested and being put to no use; a large premium to pay on the incorrect design of inlet. It is probable that basins are in existence in which less than one-half of the volume which should be available is effective and the inlet and outlet would utilize the full working capacity of the tank and increase its utility. It will be seen that to obtain ideal conditions.
of flow, a piston-like movement of a vertical section of water is important.

The devices for the entrance of water into a tank may be grouped in two classes: weirs and orifices. The weir has the advantage over the orifice in that the distribution of the influx may be extended over the entire cross-section of the breadth of the tank, and thus uniformly distributed literally; but this does in no way provide for the distribution of the influx through out the depth. This is an evident shortcoming of the weir for use as an inlet. However, it is essential in both settling basins and reetie tanks a constant level be maintained. This is usually accomplished by providing a weir at the outlet. It may be so baffled as to prevent the effluent from running off of the immediate surface. This is a common method of arrangement, orifices at entrance and a weir at exit. An examination of various articles in
While the engineering periodicals show this to be true for certain tanks, of twenty such tanks described, eighteen have this arrangement and the other two have devices not entirely different, but falling under classification of slotted pipes as patented by the Common Septic Tank Company.

To ascertain the characteristics flow of water through orifices, and the effect of the shape of the orifice upon the distribution of the influx throughout the cross-section of the tank, a series of experiments were made. These will be explained and discussed, and the information gained will be applied by suggesting forms and limitations for inlets and outlets of reservoirs.

II. Experimental.

An aquarium, a prismatic vessel, with glass sides and ends, whose cross-section was 12" x 12" and length 20" was fitted with a partition wall about 7½" from one end. At the mid-point this partition was located an orifice, through which a flow might be created from
one chamber into the other. A tube in the
smaller compartment served as a means
of supply of water. The water might
then be drawn from the end of the
larger compartment by means of a
siphon tube, thus creating a flow
through the surface. By adjustment
of the siphon a condition may be deter-
mined at which a constant level would
be maintained. Filling the two chambers
with water, the water in the smaller
one was colored a vivid green by means
of fluorescein, a strong coloring matter
which readily unites with water. Then
starting a flow through the surface in
the manner described above, it was
possible by observing the path of the coloring
matter to determine the character of the
flow in reference to distribution. It was
necessary to have some standard condition
prevailing so that these results might
be comparable. This condition, observed in
one experiment with this tank was that
the line separating between the occurrence of
influx of the coloring matter until exit
Experiment 1. Figure 1 represents the apparatus as assembled and the section which, as shown, was shaped like the frustum of a frustum, extending from \( \frac{3}{4} \times \frac{3}{4} \) to \( 1\frac{1}{2} \times 1\frac{1}{2} \). The sides formed an angle of \( 70^\circ \) with the horizontal axis, a level within \( 1\frac{1}{2} \) of the top of the tank was maintained. The flow, as shown, expanded so that in its largest section it occupied about one third of the section of the tank. A consecutive sketch of the observations is shown in figure 2.

Experiment 2. The level of the water was then reduced to the middle of the surface and the supply decreased so that the former velocity of two minutes for the flow was again obtained. Under these conditions, the distribution throughout the breast was quite complete but not so throughout the depth. The flowing water clung to the surface and seemed inclined to climb over the top in a sheet. The consecutive result of the observations is shown in figure 3.
Experiment 3. The same two experiments were
again performed with a rectangular slot
orifice, about 1 1/2 x 1 1/2 in size. The line
of this orifice were sharp and the
stream issuing from it was undisturbed
and distinct. The result of this two
observations as shown in figure 3, indicate
that a horizontal distribution is more
easily accomplished than a vertical
distribution.

Experiment 4. When the orifice was cut
merged to the middle of the tube, it was again
evident that the flow has a tendency to
occur in a film over the surface. This
is clearly illustrated in figure 4.

These results were in a measure verified by the following experiments
conducted on a larger scale.

Experiment 5. Coloring matter was introduced
into a six inch pipe, thirty inches long,
which connected two chambers of a
larger size. This apparatus is shown to
scale in figures 5 and 6. In the first case
the pipe had no expansion at its outlet
and the course of the water was directly
parallel to the horizontal axis of the pipe until it struck against the wall at the end of the chamber. This is shown in Figure 5.

Experiment 6. In the second case the pipe had an expansion on its mouth that increased its diameter from six to ten inches in a distance of eight inches. The pipe makes an angle of 14° with the horizontal axis. In this case the flow was not concise but broken and inclined to spread as it left the orifice in a way similar to its action in the corresponding experiment when performed on a smaller scale.

Experiment 7. This orifice was then replaced by another which increased in diameter from six inches to eight and one half in seven and one half inches. This made an angle of 10° degrees with the horizontal axis of symmetry. The orifice caused in a manner similar to the last experiment an expansion of the flow.
However it was evident the flow down to the sides of the orifices, a thing that did not occur with the larger orifices. The cause of this is probably the decreased increase for an orifice of this nature. One of a higher degree would be inclined to cut the water in figure 8 and not direct it on the diverging path. The velocities in these cases were about one foot from second.

Experiment 3. Experiments of this nature were done with the two styles of orifices. Experiment 2 with the water line at the center of the figure. These are shown in figures 8 and 9. It was again possible that the water is inclined to return on the surface and not move the zones below the inlet.

The introduction of coloring matter was accomplished by means of a series of nozzles inserted in the inlet of the tube. These were connected to a reservoir of coloring matter. The entire was composed of ¼ inch pipe and illustrated in figure 7.
III. Discussion of Experiments

Viewing the subject from an approximate mathematical standpoint, we have the following:

General Data for Small Tank:

Cross section of the tank = 1 sq. ft.

Expanding orifice = 0.0039

Rectangular = 0.0052

Rate of water flowing through tank = 0.00026 cu.ft/sec.

1 lb. in 1 min.

Experiment I, Figure I

Velocity = \( \frac{\text{Quantity}}{\text{Area}} \)

Velocity at orifice = 0.0039 = \( \frac{1}{4} \) ft/sec.

Assuming area at a, \( \frac{1}{3} \) of entire, velocity at a = \( \frac{0.0026}{0.33} \) = \( \frac{1}{4} \) ft/sec.

Assuming area at b, \( \frac{1}{4} \) of entire, velocity at b = \( \frac{0.0026}{0.25} \) = \( \frac{1}{4} \) ft/sec.

Average velocity in tank = \( \frac{\frac{1}{4} + \frac{1}{4} + \frac{1}{4}}{3} \) = \( \frac{1}{4} \) ft/sec.

Actual observed velocity = \( \frac{3}{4} \) ft/min = \( \frac{1}{80} \) ft/sec.

Comparing the two velocities, \( \frac{1}{40} \) ft/sec and \( \frac{1}{80} \) ft/sec.; thus when the condition that areas at a, b and c are representative, it would indicate that the areas are actually larger than those assumed.
Experiment 2, Figure 2.

\[ \text{velocity} = \frac{\text{Quantity}}{\text{Area}} \]
\[ \text{Quantity} = 0.00173 \text{ cu. ft./sec.} \]

\[ \text{velocity at surface} = \frac{0.00173}{0.6 \times 0.039} = \frac{1}{44} \text{ ft/sec.} \]

Assuming area at 2, 1/4 of whole, velocity at \( a = \frac{0.00173}{0.6 \times 0.6} = \frac{1}{70} \text{ ft/sec.} \)

Assuming area at 6, 1/6 of whole, velocity at \( b = \frac{0.00173}{0.6 \times 0.6} = \frac{1}{550} \text{ ft/sec.} \)

Average velocity = \[ \frac{\frac{1}{44} + \frac{1}{70} + \frac{1}{550}}{3} = \frac{1}{116} \text{ ft/sec.} \]

Actual velocity = \( \frac{1}{80} \text{ ft/sec.} \)

Comparing the two velocities \( \frac{1}{116} \text{ ft/sec.} \) and \( \frac{1}{80} \text{ ft/sec.} \), they show the condition that areas at \( a, b, \) and \( c \) are representative; it would indicate that the areas were actually smaller than assumed.

Experiment 3, Figure 3.

\[ \text{velocity} = \frac{\text{Quantity}}{\text{Area}} \]
\[ \text{Quantity} = 0.00173 \text{ cu. ft./sec.} \]

\[ \text{velocity at surface} = \frac{0.00173}{0.6 \times 0.3} = \frac{1}{80} \text{ ft/sec.} \]

Assuming area at 2, 1/6 of whole, velocity at \( a = \frac{0.00173}{0.6 \times 0.6} = \frac{1}{935} \text{ ft/sec.} \)

Assuming area at 6, 1/6 of whole, velocity at \( b = \frac{0.00173}{0.6 \times 0.6} = \frac{1}{935} \text{ ft/sec.} \)

Average velocity = \[ \frac{\frac{1}{80} + \frac{1}{935} + \frac{1}{935}}{3} = \frac{1}{85} \text{ ft/sec.} \]

Actual velocity = \( \frac{1}{80} \text{ ft/sec.} \)

Comparing the two velocities \( \frac{1}{85} \text{ ft/sec.} \) and \( \frac{1}{80} \text{ ft/sec.} \), it shows when the condition that areas at \( a, b, \) and \( c \) are representative, it would indicate that the areas at these points were actually the same as those assumed.
Experiment 4, Figure 4:

\[ \text{Velocity} = \frac{\text{Quantity}}{\text{Area}} \]

\[ \text{Quantity} = \frac{0.00173 \text{ cu ft}}{\text{sec}} \]

\[ \text{Velocity at surface} = \frac{0.00173}{5 \times 0.065} = \frac{1}{58.5} \text{ ft/sec} \]

Assuming area at 1/6 of whole, velocity at a = \[ \frac{0.00173}{5 \times \frac{1}{6}} = \frac{1}{470} \text{ ft/sec} \]

Assuming area at 1/6 of whole, velocity at b = \[ \frac{0.00173}{5 \times \frac{1}{6}} = \frac{1}{470} \text{ ft/sec} \]

Average velocity = \[ \frac{1/58.5 + 1/470 + 1/470}{3} = \frac{1}{138} \text{ ft/sec} \]

Actual velocity = \[ \frac{1}{80} \text{ ft/sec} \]

Combining the two velocities \[ \frac{1}{138} \text{ ft/sec and } \frac{1}{80} \text{ ft/sec} \]

Then from the condition that the areas at a, b and c are representative, it would indicate that the areas were actually smaller than assumed.

Experiments 5, 6, 7, 8 and 9.

These experiments substantiate the general result obtained and observed in the first four experiments. They verify the fact that the expansion of an orifice caused an expansion and divergence of the stream from it. However, it was observed that with a too rapid a flow or divergence of the sides of the orifice, the flow will not continue in the lines directed by the orifice. This was the result with the 14° expander. However, the one with the
smaller angle shows that ten degrees angle of divergence will give good results. It did not cut the flow but the water seemed to cling to the sides of the orifice and continued to expand often leaving the orifice. This is an invaluable feature and upon it the completeness of the orifice and the free direction of the current depends. The value and applicability of the orifice. These four experiments also verified the observations on the smaller experiments concerning the dripping of the water over the surface when the orifice is not submerged. It is very evident that water when subjected to these conditions has a decided tendency to flow in a film over the surface and not to be distributed to any considerable depth.

IV. General Discussion

The average of the conducted and observed velocity in the tank used in experiment I was \( \frac{3}{4} \) of a foot per second, or one foot per minute. This velocity in a tank one hundred feet long would result in an actual flow of an hour and three quarters. Even then within
The range of probable velocities in an aeration tank or settling basin, and shows the applicability of the results of the experiments to actual conditions. The details of the design of the orifice will now be discussed. It has been shown that the desired distribution of flow may be obtained by means of a trapezoid shaped orifice. A relation governing conditions on dimensions will now be derived.

Let us consider the orifice shown in the accompanying illustration. The law is to occur in the direction indicated by the arrows. The thickness of the wall in which it is to be placed may be taken as $t$. Then consider the dimension of the square representing the inlet to be a side of the one cut.

The angle of diverging sides with the conical section is $2\theta$. The experimental orifice which proves in the most satisfactory in experiment 7 was the one degree expanded. This orifice increased in diameter from
six to eight and one half inches in seven
and one half inches. The ratio of the
smallest to the largest cross section was
then \( \frac{2}{3} \) on \( \frac{1}{2} \).

It has been demonstrated by Messrs.
Niley and Robinson at the University of
Illinois that there is little loss of velocity
heat in the occurrence of 90° flow through
the ten degree exchanger.

Setting the above ratio govern the
example under consideration, the equa-
tion \( b^2 = 2a^2 \) would represent conditions.
It may be seen from the figure that
\( \tan \theta = \frac{b-a}{2t} \). As ten degrees has been de-
ed upon as the desirable angle, let us
substitute its tangent \( \theta \) in the relation
derived

\[
\tan \theta = \frac{b-a}{2t}, \text{ or } \frac{b-a}{2t} = \theta, \text{ or } b-a = 4t.
\]

Now as \( b = 2a^2 \), \( b = 17a \).

Substituting \( \frac{17a}{2} \) for \( b \), we have

\[
(17-1)a = 4t \text{ or } (17-1)a = 4t.
\]

This gives approximately \( a = t \).

This relation interpreted states that for
the condition that the area of the outlet
is twice the area of the inlet and the angle
of expansion is ten degrees, the side of
the square inlet will be equal to thickness
of the wall.

The feature of the flow through a
semi-submerged orifice has been discussed
and may be defined as surface skinning.
It is evident that the momentum of the stationary
water is so great that the velocity of the
inflowing stream will be expanded upon
the surface water than in putting the
water through out the defil in motion.

Should any such means of inlet be used
it would be necessary to provide an efficient
system of baffling. Baffling could
scarcely accomplish the desired result,
so it is true that water will flow under
a baffle in a manner similar to the flow
over a submerged weir. The momentum
of the stationary water again causes the
velocity to be expanded over the surface of
the tank and directly next to the baffles.

This is shown in the accompanying figure. So it will be
seen that baffles will not create
that condition of ideal flow
we are now designing to accomplish.
V. Application to design.

The application of these features of design to reservoirs will now be considered. Having decided upon an orifice of expanding section and upon the proportions governing its dimensions and form, we will now investigate the shaping of the orifice. It is desirable to get the flow from the individual orifices into a unit flow, or uniform current over the free depth in the shortest length possible. This is a matter of decided economy in the capacity of the outlet.
In the figure on the preceding page, the spaces are the "useless intervals" which in no way contribute to the performance of the tank's duties. These spaces increase in size as the spacing of the orifices is increased. Thus, it may be seen that the economical spacing involves the comparison of the cost of the tank per linear foot and the cost of the construction of an orifice. It has been shown that the spacing can only be designed by careful consideration of this comparison. However, there is a minimum desirable distance between orifices so that close spacing would be uneconomical. A spacing equal to the depth of the tank or reservoir is recommended. In this case the horizontal expansion required would be equal to the vertical expansion in a condition quite satisfactory to distribution. In this case the flow from the various orifices would become unified at a distance from the orifice equal to two and one half times the depth of the tank, or the spacing of the orifices. However, it would not be definitely disad
vantages to the process of the tank in
brain if the horizontal expansion were
considerably in excess of the vertical
expansions, as the latter is limited
by the surface of the water and the
bottom of the tank.

In the figure on page 17 it is shown
that the duct to be a channel of considerable
width. This is necessary to insure an equal
substitution of water at all orifices and a
low velocity at the entrance to the orifice.

The device for the exit of the water
from the reservoir is also to be considered.
It is nearly as important that the water leave
the tank in a vertical sheet as it is that
it enter in this manner. If the water
is drawn off over a weir at the extreme
end, it is sure to disturb the conditions
of flow installed at entrance. If it drawn
over a weir and from under a keel it will
reflect it in a similar manner, but not to
such a marked degree. Experiments con-
ducted at the University of Illinois
have demonstrated that a contrac
ting orifice will collect the water from a
surprisingly large area in the process
of "running through." Such a device as
shown in the accompanying illustration
as recommended.

The entrance, consisting of a round angle of forty-five degrees, will collect the water from the entire sectional area, and the weir will maintain a constant water level, a thing usually desired in works of the character under consideration.

Figure 10 shows an application of the conclusions concerning orifice as a means of entrance and exit of the liquid into a reservoir. The features embodied are:

1. The entrance orifice is expansive in cross-section, its sides making an angle of ten degrees with the horizontal axis.
2. The smallest dimension of the orifice is equal to the thickness of the wall in which it is placed.
3. The entrance orifice is located midway between the surface of the water and the bottom of the tank.
4. The horizontal spacing is equal to the depth of the tank.
5. The outlet orifices are constrictive in cross-section and the sides make an angle

...
Of forty-five degrees with the horizontal.

6. The outlet surfaces are located in the end walls, in positions similar to the inlet surfaces.

7. The constant water level is maintained by a weir wall behind the outlet surfaces.

Some practice deviates widely from the recommendations made in the previous paragraph.

Considering a specific case of a representative continuous sedimentation basin, the one operated in connection with the water filtration works at Albany, New York. The inlet and outlet fifteen range along the opposite long sides of the rectangular shaped basin. The tank is nine feet deep and the inlets are fifty-five feet apart. The distance between the inlet and the corresponding outlet is about three hundred and seventy-five feet. The general form of the inlet is a vertical over-flowing pipe extending four feet above the surface of the water. The outlet is a similar pipe two feet below the surface. It is believed that under certain conditions of inlet and outlet, the resins
conditions of uniform velocity imperative to the efficient function.

The aeration tank to be constructed in connection with the sewage disposal works at Columbus, Ohio, was, as previously expressed, the feature herein recommended. The tank is divided into compartments forming a primary and secondary system. The inlets and outlets are both exceedingly simple, but consist simply of circular sluice gates. They are spaced about fifteen feet apart; the depth of the tank fluctuates from twelve to nine feet. These sluice gates are twenty-four inches in diameter and it may be supposed that the flow will be similar to that portrayed in Figure 3.

Engineering has been defined as "economic construction," and an engineer worth his title should strive for improvements involving economic gain. This subject considered, is a feature of engineering which, it is believed, has not received the attention and care warranted by its importance and the expenditures involved.
Fig. 1.

Side View.

End View.

Scale 2\"=1\"
Device for introducing coloring-matter into orifice.
Fig. 8.

Fig. 9.

Scale 2' = 1"
Fig. 10.