THESIS REPORT

Design and Test of

a

Model Siphon Spillway.

by

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INDEX

1 Spillways in General.

In its ordinary use the spillway is a devise for removing excess or surplus water from a resevoir or canal, in order that the water level within the resevoir or canal may not rise above the point considered safe or fixed upon as the maximum allowable height. When used to discharge water from a canal it discharges the water when it becomes filled above its normal capacity. Such a spillway by the very nature of conditions must be automatic in its action and absolutely reliable. It serves as a safety value to prevent the canal being overloaded and its banks topped and washed away. The spillway must be so located that the water may be diverted quickly and without damaging the adjacent land. It should be easily accessible and provide for the greatest degree of effeciency possible.

In the design of the ordinary spillway we must consider two factors; first, the maximum quantity of water to be discharged and, secondly, the maximum rise above the normal water surface which is to be expected or rather that the structure, whether it be a canal or a dam, will stand. Having established the discharge and head of water available the length of spillway required may be computed by using the standard weir formula,

$$Q = KBH^{3/2}$$

in which,

Q = Quantity of water discharged in cubic feet per second.

K = A constant or the efficiency.

B = Width of spillway

H = The effective head or the distance from the crest of the spillway to the water surface.

In order to provide for a safe foundation the spillway should, in general, be located where the canal is well in cut. The design of a spillway is largely controlled by surrounding conditions. In the case of a storage dam the spillway location is controlled by the natural slope of the land that leads away from the spillway.

The chief criticisim in the past has been that spillways have not been built with sufficient capacity for the extraordinary floods. Provision has been made for high water in most cases but the failure of many dams shows that the extraordinary flood of the century has not been provided for. It must be remembered that during the life of the structure there may occur some combination of rainfall or melting snow which will produce a flood exceeding any previously known maximum. It is this flood that the designer of a spillway must provide for.

An example which will illustrate this point is a project on the Cache Creek, a tributary of the Sacramento River, California. Observations indicated a maximum flood of about 20,000 sec. ft., but from various indications, one of the engineers figured out a possible, although improbable, flood during earlier years reaching 60,000 sec.ft. This figure was regarded as absurd, but nevertheless the spillway was designed for a capacity of 60,000 sec.ft. It had hardly been finished when a flood occurred of approximately 65,000 sec. ft. Had not the spillway been designed for this capacity it would undoubtedly have been swept away.

In San Diego, California, they were not so fortunate, for when the big flood of 1916 came the dams at Sweet water and at Otay, which had nowhere near sufficient spillway capacity, were washed out causing tremendous loss to the city both in lives and in capital, to say nothing of prestige.

The safest and only correct method of designing a spillway is to make a very thorough and complete study of all the rainfall data available and assume the very worst conditions possible then add a sufficient factor of safety and ~~then~~ design the spillway for this capacity.

There are two general types of spillways, namely, overflow spillways and siphon spillways. The distinguishing features of the two types are that the capcity of the overflow spillway depends on the length of crest and the height of water above the crest and is increased in no way by the distance through which the water falls below the crest; on the other hand the capacity of the siphon spillway depends on the area of cross section of the smallest part of the siphon and the difference in elevation between head water and tailwater. In other words the siphon utilizes the fall (below 33.9 feet) to increase the capacity while the overflow spillway makes no use of this fall.

2 Siphon Spillways.

In Europe siphon spillways were used as early as 1870. The first types required the use of an ejector to cause them to function properly. As soon as the water rose above its normal level the ejector came into action and sucked the air from the siphon proper which consisted of a large pipe. The ejector made possible the functioning of the siphon long before the water had risen above the level of the bend.

The presence of the smaller pipe, which is necessary to set the siphon in operation forms a weak point in the arrangement since it is liable to become choked with debris or its action impaired by frost. The circular section is also undesirable from an economic standpoint and renders it impracticable except for small diameters.

The credit for the design of the first siphon spillway without an ejector goes to Heyn, a German civil engineer. Fig.I shows one of his siphons. It is built of riveted sheet iron and is simply fixed on a floodgate in an irrigation canal. Under test it showed an effeciency of about 50%.

The action of this siphon depends on the fact that the water at the beginning in a small stream along the lower surface of the crest of the siphon draws with it more and more air from the upper part of the siphon and this quickly brings the siphon into operation.

Contemporaneously with Heyn, Gregotti of Italy constructed spillways without ejectors. He demonstrated their applicability under the most varied circumstances and perfected their construction by the use of reinforced concrete. Figure II. shows two types especially favored by Gregotti.

In France a higher state of developement and more effecient functioning was obtained by using reinforced concrete and proportioning the different parts to effect this effeciency.

Fear of interference with operation during freezing weather was the chief reason for American engineers failing to adopt this type of spillway but a modificationof design led to the overcoming of this defect and to its subsquent adoption in this country. This menace was obviated by lowering the intake leg below the normal surface of the water and the draining of the sealing basin. This also prevented debris collecting or lodging at the throat.

The use of siphons as spillways is much more recent in this country than in Europe. The first to be built in this country was on the New York state barge canal. More recently they have been constructed on several projects of the U.S. Reclamation Service and on many California irrigation projects. Some of the more notable examples are Orland, Salt River, Guma, and Sun River of the Reclamation Service; the South San Joaquin Irrigation District, Sweetwater dam near San Diego,and the Southern California Edison Co. at Huntington Lake, California.

As previously stated, the height utilized to produce flow in an overflow spillway is figured from the surface of the water above the spillway to its crest. The available head is from the water surface above to the water surface below the dam. In the siphon, however, flow is produced by a head equal to the difference in elevation of the water surface at the inlet of the siphon and the elevation of the water at the outlet end. If the outlet is not submerged it is measured to the center of the outlet opening.

The tendency has been, in most cases, to assume that heads in excess of 34 ft. were not adaptable to siphon installation because it was accepted that the limit of vacuum draft had been reached at that point. Some siphons have been built with heads in excess of 34 ft. and in specific cases with heads as high as 52 ft. Most engineers agree however that 34 ft. is the limit of vacuum draft.

There are two general forms of siphon tubes, the first has a throat and outlet of equal cross section but not necessarily of uniform shape. This type is rather common in Europe and was followed to some extent in the develepement of the Ocoee River project in Tennessee.

The second type has a contracted throat section and expands with a divergent tube as an outlet to overcome local losses of head and other contributing defects. This is the type most generally used in siphon design in this country and also in Europe at present.

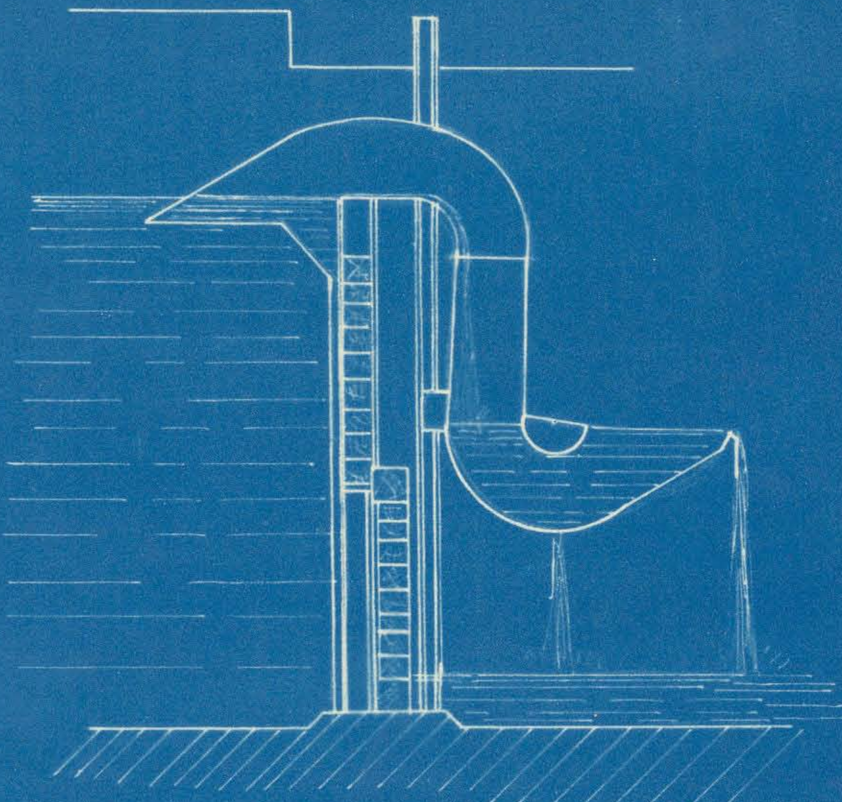


FIG. I

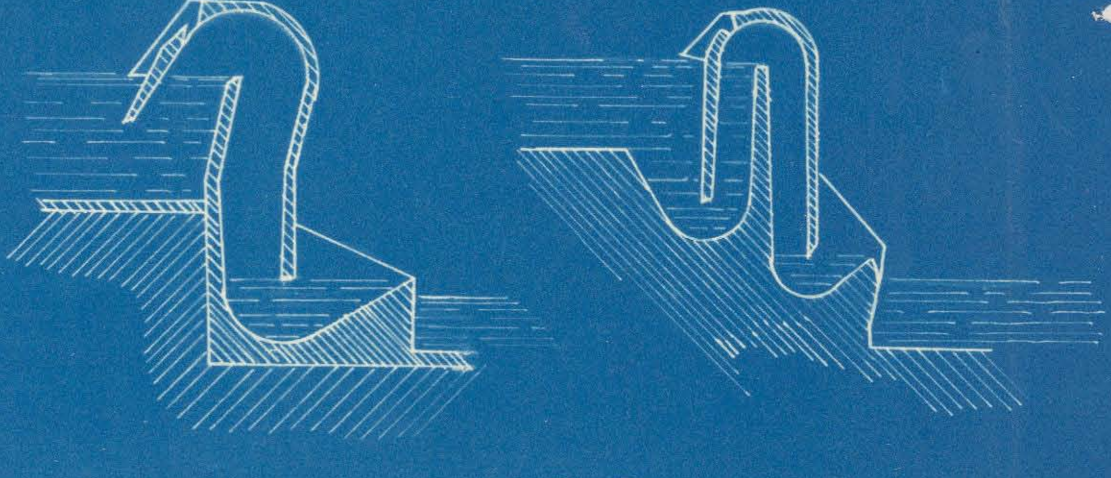


FIG. II

There is hardly any available data to aid the designer in the determination of either the size or shape of the vital parts of the siphon to realize maximum effeciency and proper functioning. The great cost involved and the greater risk of failure discourage most designers from departing to any marked degree from the prevailing practice especially as they have no assurance of increased effeciency or accomplishment of the desired purpose.

No experiments have been made to determine other then the overall effeciency. Practically nothing is known of the relative losses in the various parts of the siphon. It is readily seen that a slight change in some part of the siphon might greatly effect the overall effeciency. This is indeed a field that might well be explored. It is true, no doubt, that the overall effeciency is what is desired but to insure economic design the effeciencies of the various parts would be very desirable.

The formula used for calculating the effeciency is-

$$Q = KA\sqrt{2\,gh}$$

in which

Q = Quantity of water discharged expressed in cu. ft. 1 sec.

K = A constant or the effeciency of the siphon

A = The cross sectional area of the throat or smallest section expressed in Square Ft.

H = The fall expressed in ft.

The siphon spillway was first introduced in this country by G.F. Stickney on N.Y. State Barge Canal. Since then many experiments have been conducted and the siphon has been improved and developed so that now it is used to discharge far greater volume than was originally contemplated. The discharge through a closed conduct, as previously stated makes it possible to utilize the fall at a dam to increase the velocity and consequently the quantity discharged. The siphon is put into operation by a slight rise of the water. The fluctuation of the water above the normal stage and is restricted within narrow limits.

The rate of discharge over a dam depends on the depth of water on the crest, increasing as the depth increases and hence an overflow spillway may not have much discharge capacity until the water surface rises to a considerable height. Such a spillway is not immediately responsive to variations in the stream flow and does not closely control the water level.

Although siphons were known to the ancients and have been utilized for hundreds of years, their use was confined to small tubes, of an inverted U-form, for conveying liquid over the edge of a vessel and delivering it at a lower level; it is only within recent times that the siphonic principle has been applied to conduits of large size and capacity, for discharging at a dam.

The action depends on the difference in pressure at the extremities of the conduit, the flow being toward the lower level and ceasing when the levels coincide or when air collects at the highest part of the conduit. In order to pass water over the summit of the siphon higher than the upper water surface, it is necessary to utilize the air pressure on the water surface. A clear idea of siphonic action may be had if it is understood that the flow is due to the push of the air on the upper water surface. This proves that the maximum head available is 33.9 ft. which is equivalent to a pressure of 14.7# per Sq. In.

A siphon in operation, and acting under the siphonic head or less, will continue in operation as long as the inlet is submerged sufficient to prevent the admission of air, whether or not the outlet be submerged. This is due to the fact that the water is flowing at such a great velocity that air bubbles cannot rise in the lower leg against the outflow. The problem is thus resolved into the devising of methods for priming the siphon.

A siphon that is sealed against the entrance of air, will be primed when there is sufficient flow thru the conduit to absorb and carry out the air entrapped therein. In some siphons it is necessary that the lower leg be sealed by discharging below the lower water surface or by a sealing basin at the end of the leg, whereas others discharge freely and are sealed by a jet of water in the siphon. In order that the inflow velocity and consequently the entrance loss be small, the inlet to the siphon should be large.

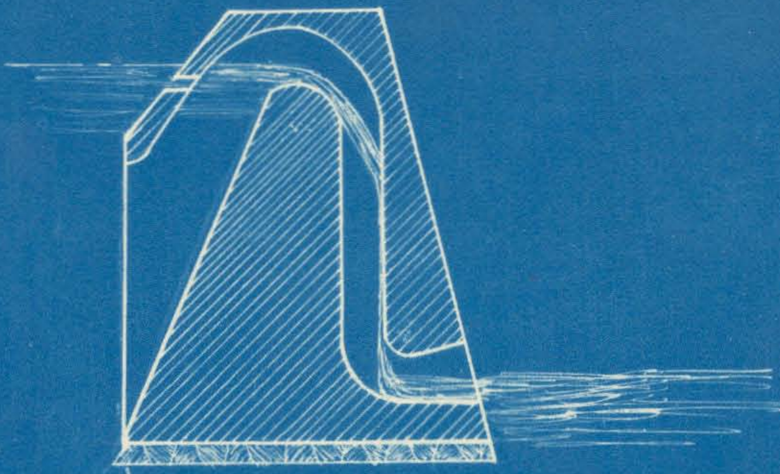


FIG. 1

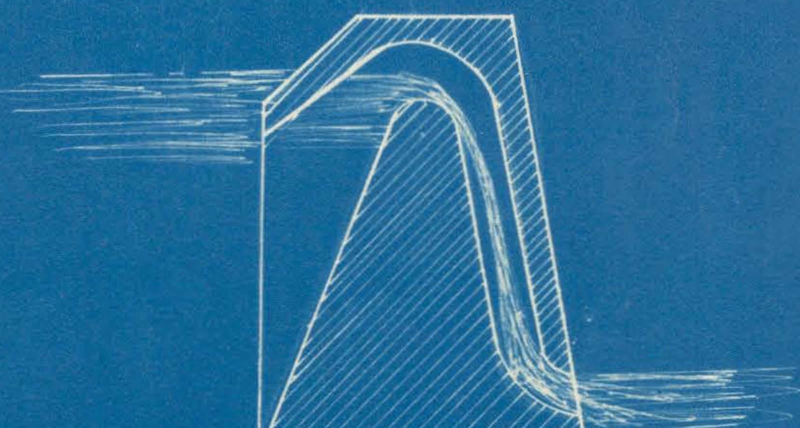


FIG. 2

The inlet should also be placed well below the water surface in order to exclude floating matter which might clog up the conduit. The upper leg should taper gradually from the inlet to the minimum section, called the throat, at the top of the lower leg. The upper bend, called the crown, should be curved and of moderate radii to reduce friction loss. The lower leg may be either inclined or vertical. The outlet should be flared upward so that air bubbles, rising thru the water while the siphon is priming, may be deflected outward.

Fig. 1 shows a siphon with vertical lower leg. The water rises above the air vent, sealing it against the admission of air, and spills thru the crown of the siphon, forming a jet at the throat that jumps across the lower leg. This jet makes a diaphragm of water which seals the upper part of the siphon against the entrance of air from below. A certain quantity of air is entrapped above the jet in the crown of the siphon and this air is absorbed and carried out by the flowing water. It is not necessary to eliminate all the air to induce priming; the removal of a small part is sufficient to start action.

A siphon with slightly inclined lower leg and a sealing basin at its bottom is shown in Fig. 2. A rise in the water level above the dam seals the upper end of the siphon and produces a flow of water thru the conduit which fills the sealing

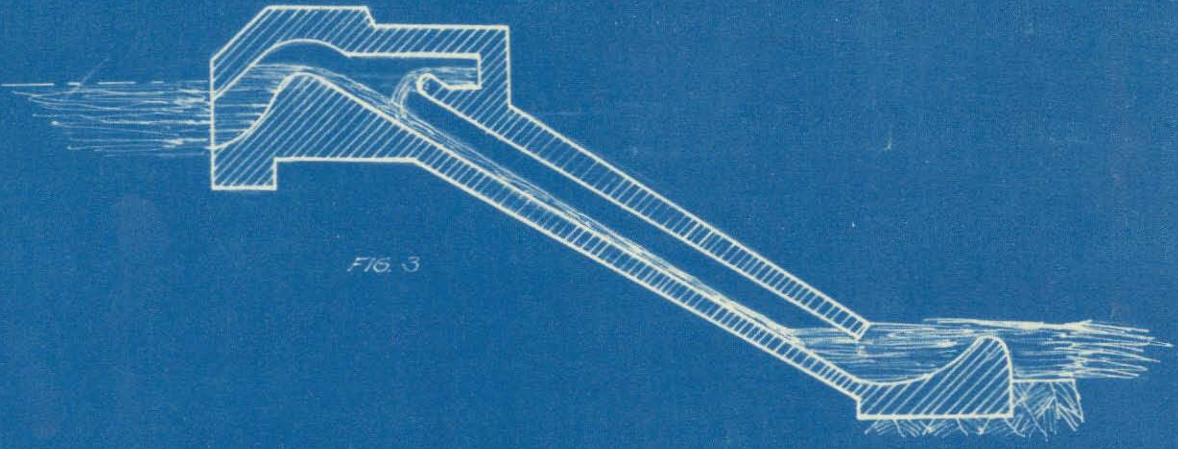


FIG. 3

FIG. 4

basin and thus seals the lower end. A jet of water is formed at the crown of the siphon which plunges into the water of the sealing basin, carrying air absorbed from above, and this air is carried outside the conduit, before bubbles can rise thru the water. As in the previous case priming is a progressive process and is quickly accomplished.

Fig. 3 shows a siphon with the lower leg on a flatter slope and terminating in a sealing basin. In this case, the inclination of the lower leg does not admit of a jet being formed directly. Recourse is had to an auxillary channel where jets are formed, that seal the upper part of the siphon. This causes the upper part of the siphon to prime and produce flow in the lower leg which carries out the air and primes the lower portion. The sealing basins are provided with small pipes to drain them of water when the siphons are not in operation, so that they will not become clogged with ice in cold weather.

Another type of siphon with an inclined lower leg, which doen not require a sealing basin is shown in Fig. 4. In this siphon a curve is formed in the plane of the back wall of the lower leg, near the bottom, such that the water flowing thru the conduit will be deflected, and a jet will be formed that will jump across the leg. This jet makes a diaphragm of water which seals the leg against the entrance of air from below and causes the siphon to prime.

All the previously described siphons prime when there is a slight rise of the water level above the dam, the rise varying from 3 in. to 1½ ft. depending on the size and the type of the siphon.

Some types of siphons require submerged outlets, but sealing basins as a rule are objectionable and should be dispensed with if possible.

When the water rises in the sealing basin, the air entrapped in the siphon is compressed, which may, unless relieved, retard or completely prevent priming. Also when priming starts there is a pulsation in the flow, due to air rising inside the siphon from the water of the sealing basin and restoring a part of the volume previously taken away.

The sealing basin reduces the effective head somewhat and requires considerable additional masonry, thus increasing the cost of the structure.

During the operation, the shell of a siphon is under pressure, the intensity depending on the head. The air pressure tends to collapse the walls on the conduit, this, however is offset to some extent, by the fluid pressure within the siphon. The pressure at the inlet is equal to the pressure of the atmosphere(33.9 Ft.) plus the head of water above the inlet. At the crown the internal pressure is practically zero, if the siphon is acting under the maximum siphonic head, and in such case the unbalanced atmospheric pressure will amount to 2117# per Sq. Ft. The effective outside pressure decreases almost to zero at the inlet and at the outlet.

It has not been possible to derive a satisfactory formula for the flow thru a siphon that will take all the factors into consideration for the simple reason that no formula or expermental data for determining the loss of head at the bends etc. is available.

The Sweetwater Dam, near San Diego California, has an overflow spillway at one end and a siphon spillway at the other, There are six siphons, each six ft. high by twelve ft. wide, acting under a head of 33.5 ft. The inlets are twelve ft. high by 8.5 ft. wide. The lower legs, which are inclined, are of practically uniform area throughout, varying from six by twelve ft at the throat to 8.5 by 8.5 ft. at the bottom and terminate in a sealing basin. The discharge capacity of this spillway is estimated to be about 1200 cu. ft. per sec. Some of the uses which a siphon spillway may be adopted with advantage are as follows:-

1. To regulate the water surface in a stream above a dam at the highest permissable level, giving the maximum head for power developement, the maximum storage, the greatest navigable depth, and reduce the fluctuation of the water surface to a minimum.

2. To provide an outlet from a flume or forebay when a contrast flow is maintained, which will operate with a slight raise in the water surface and will discharge the entire flow, in case of sudden shut down of the power plant or a sudden obstruction of the flow

3. To use in place of gates valves to discharge water from a reservoir. The crown of the siphon may be placed entirely above the water level, so that no

leakage is possible, and the siphon be arranged to be operated by the manipolation of small hand valves, thus avoiding the use of low and cumbersome gate hoists.

3 Advantages of Siphon Spillways

The greatest advantage of the siphon spillway is the economy of ground space and construction cost, due to the greater quantity of water which can be controlled in the same space and with the same variation in head. To bring out this point more clearly let us sight an example. In the Turbigo hydroclutin plant, near Milan, an ordinary overflow spillway is used. Near Verona a siphon spillway is in use. They both have practically the same discharge, 3000 and 2800 cu. ft. per sec. respectively. The Veron spillway works from a face 59 ft. in length and 3" is the greatest variation in water level. On the other hand the spillway at Turbigo is 300 ft long and a rise of 2 ft is necessary before the quantity of water required flows over.

Rapidity of control is another advantage of the siphon spillway. A variation head of only a few inches causes the spillway to at full capacity. Whereas the overflow spillway does not become fully effective until the danger point is reached.

The siphon spillway is purely automatic and does away with the human element, which is often times an advantage.

Some engineers were afraid that the siphon spillway would not function properly in cold weather. These fears were largely exaggerated and by lowering the lip of the spillway the danger of being clogged by ice ~~of~~ or debris had been largely, if not totally, done away with.

4. Siphon Spillway Problems.

Although the siphon spillway has been used in Europe and America for many years , nothing of a definite nature is known of the exact condition governing the design of the siphons. Practically no data is available to aid the designer in departing from the present practice to increase effeciency. Siphons in the past have been designed using the general principles of hydraulics, but the data available is vague and indefinite. There is almost no information regarding the relative losses in various parts of the siphon; the intake opening, the entrance leg, the throat, the outlet leg, the discharge loss, and the loss due to shocks and bends. It is entirely possible that a very minor change in any of the detailed parts would materially change the working of the siphon and increase the effeciency.

But the project of building a siphon is too large and costly an undertaking to experiment with unless it is absolutely certain that the change will be for the better. In other words, the men investing fortunes in the building of a siphon spillway are unwilling to depart from the general practice unless they can be assured that the new design is a better one, and is certain of properly functioning.

The following is an outline of invertigation of siphon discharge as outlined by Mr. A.L. Sonderegger, consulting Engineer.

Outline of Investigations of Siphon Discharge.

1\. A perusal of the current literature shows that in the past Siphons have been applied to regulate the elevation of a water surface, whether it be in canals or reservoirs, the idea being to secure a steady water level.

The problem which should be investigated, is the construction of a siphon which would produce a constant discharge under varying water levels.

The flood control problems in Southern California are complicated by the fact that storage reservoir sites of sufficient capacity to store the entire flood flow, are not available, and that recourse must be had to "detention reservoirs", which regulate the peak flow to such a quantity, as can be safely carried by the flood channel.

At the same time it is desirable to use such reservoirs, at least in part, for the storage of flood waters, for irrigation or domestic supply, as the combination of purposes will facilitate the financing of projects.

A study of the run-off of the various streams shows that the peaks are of comparatively short duration but very erratic; that in many instances it might be possible to utilize comparatively poor sites, if it were possible to produce an instantaneous maximum discharge through a spill-way located in the upper levels of the dam.

If the spillway is of the overflow type, its discharge will depend upon the head above the lip of the Weir, so that a considerable portion of the available storage is wasted to acquire the head necessary for a maximum flow, the discharge increasing with the square root of the 3rd power of the head (Weir formula). On the other hand, if a siphon spillway is chosen, the initial head will be possible 30 feet and an increasing head over the lip of the siphon will increase the flow in proportion to the square root of the head. While the proportionate increase is thus much less than with an overflow, it is still considerable. It is believed that a study of the shape of the outlet leg of siphons, possibly a diverging outlet, might lead to a type that would automatically stop siphon action if the head increased beyond a certain point, and beyond such point would operate like a submerged opening, that is minus the siphonic head.

It is assumed that with a siphon operating under a siphonic action of theoretically 32 ft., any head over that of the siphon lip would contribute to the discharge in proportion of the square root of the total head. (This might be proven by experiment).

2. On account of the high velocity which the water possesses when leaving a siphon, and the necessity of discharg- large volumes of water down a steep spillway, it would be desirable to have siphons with outlet legs of flat gradients, so that they may be economically constructed in the natural rock, and with the point of discharge at some

distance from the base of the dam. This is particularly desirable in Southern California, where much of the rock is shattered and must be protected from washing by water under high velocities. See Siphon at Seon- Switzerland.

The problem is to regulate the admission of air and to produce a vacuum on a flat grade. Possibly a flat gradient might also help to solve problems under item 3.

3. On account of the shock and vibration experience in the starting and stopping of large siphons it is desirable that interruptions should not be too frequent. It is conceivable that the fluctuations in the waterlevel of a reservoir, due to a varying influx, might cause a starting and stopping of siphon action at short intervals and for a considerable period of time, thereby endangering the structure. Experiments should be made with various types of siphon inlets and air ducts to cause a delay in the siphonic action until the waterlevel stands 2 or 3 feet above the lip, and to produce a siphon discharge which would continue until the waterlevel has dropped to the elevation of the lip. In this way a reservoir storage of a few feet depth would limit interruptions in siphonic action to long intervals.

It is possible that a study of different types of inlet openings and of different siphon crests will lead to a solution, combined with varying gradients of the outlet leg, with and without waterlock at the outlet.

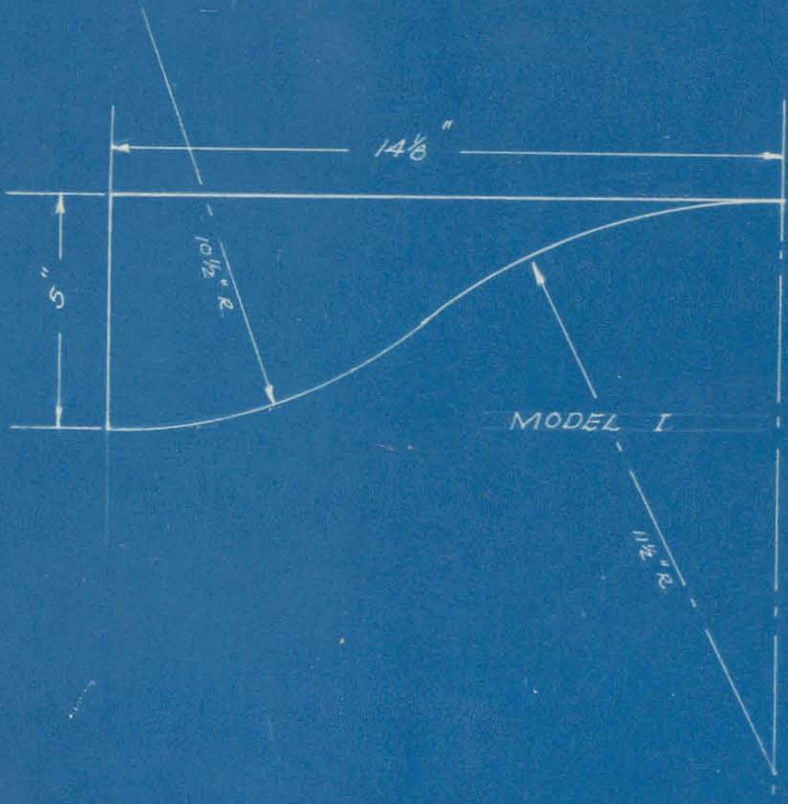


PLATE II

SCALE - ¼" = 1"

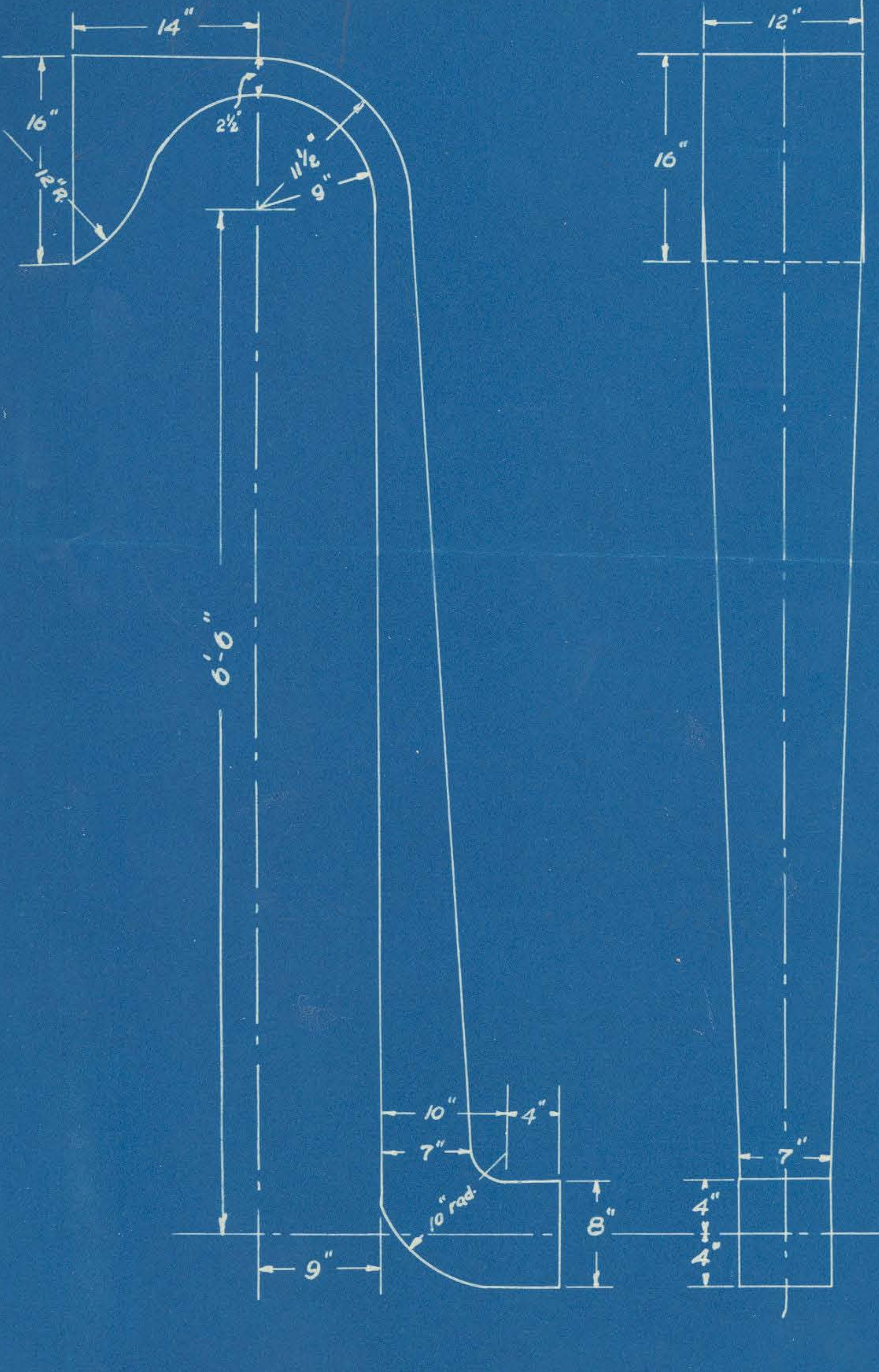


PLATE I

Siphon Spillway Model

Scale 1" = 1'

5. Tests

(a) Apparatus:-

A siphon was designed similar to the one used some years ago by Mr. R.N. Allen except that the inlet was so designed that wooden blocks could be inserted and thus vary the opening. Plate 1. shows the siphon spillway model and Plate 2. shows the two wooden blocks that were used in the tests.

It was first thought that the sides of the siphon would be made of plate glass. Such a design by the use of a lamp on the outside would make possible the visualization of exactly what happened in the various parts of the siphon during its operation. It is needless to say that this would prove invaluable for the proper design of the siphon. However complication in design, cost, and limited time, outweighed its advantages and this design was eliminated.

The plant available was two large cisterns, located in the hydraulics laboratory. These two cisterns were separated by a 12 " concrete wall in which was cut a hole large enough to place the siphon.

A siphon was put in place. Forms were then built around it and it was then cemented with a 1:1 mortar. This held it in place very rigidly.

The water was pumped from one cistern into the other by means of a centrifugal pump driven by a D.C. motor with an adjustable field, which made possible a wide variation in speed, and consequently the quantity of water pumped.

Water in an overhead tank was used to prime the pump. The quantity of water pumped could be directly measured by means of a venturi meter. The two cisterns were connected by two valves which made possible pumping from either one into the other.

(b) Tests proper:-

Tests were made on the two models; first, of the height at which siphonic action began and at the height at which siphonic action ceased, second; the time it took to prime after the height at which siphonic action began had been reached, and third; the effeciency for various values of Q.

For the first test the pump was started and water pumped into the inlet cistern until siphonic action began, the height of the water was then noted. The pump was ~~thus~~ then shut down and the height at which the action ceased was noted. It was a very simple matter to determine the exact time of the start of siphonic action as a roaring noise was very prominate.

For Test number 2, the water was pumped in, as before, and the time it took to obtain a prime after the water had reached the level at which siphonic action began was taken. The time was taken by means of a stop watch.

For Test number 3, the pump was run at various speeds. The quantity of water discharged was measured by the venturi meter previously refered to. The head under which the siphon was operating was obtained by measuring the distance of the tailwater and headwater below the reference floor and subtracting the two. Knowing the cross sectional area at the throat the effeciency, c, was determined by the equation

$$Q = cA \sqrt{2 gh}$$

where

$Q =$ Quantity of water in cu. ft. per sec.

$c =$ Effeciency

$A =$ Cross sectional area in sq.ft.

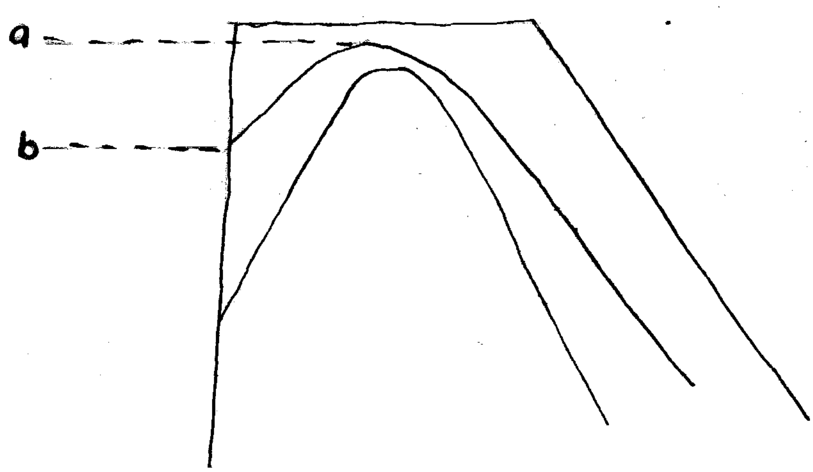
$g =$ Acceleration of gravity $= 32.2$ ft per sec

$h =$ Effective head in ft.

The tailwater was measured by a wooden float which was attached to a string and registered on a gage. The gage was calibrated and the depth of tailwater below the floor thus obtained.

(c) Conclusion:-

The results of the tests are shown in the data sheets. In the first test it is shown that by using Model 1. the siphon operated on a variation of 5 ", while by using Model 2 the siphon operated on a variation of over 7 ", It is concievable that a siphon might, if operating on too small a range, be brought into operation to frequently and the vibration thus instigated might seriously weaken the structure.



My experiments showed that siphonic action did not begin until the water reached level (a) and ceased only when the water reached level (b). It is concievable, then, that by proper design the siphon could be made to operate with practically any variation thought necessary.

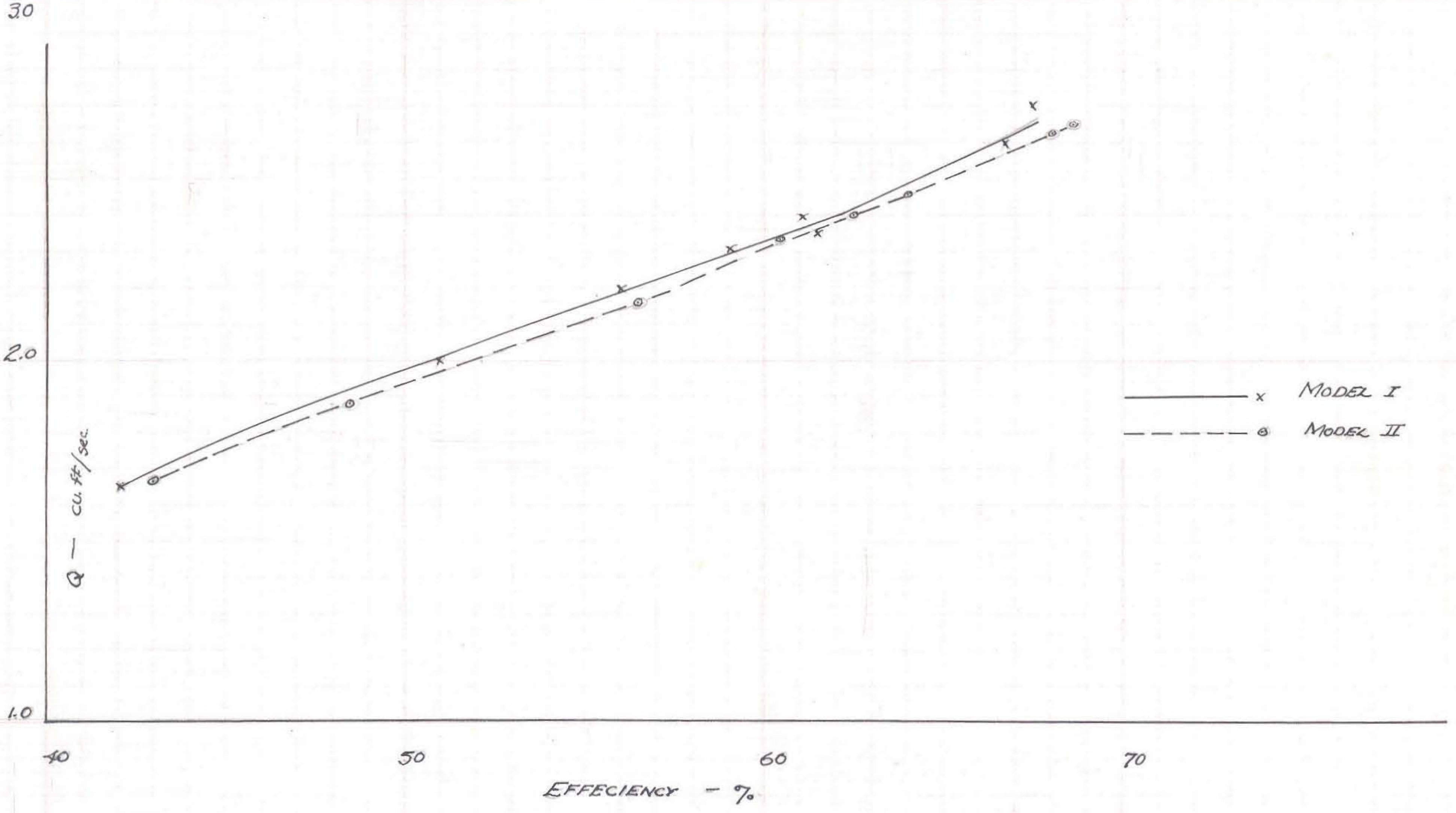
Test no. 2 brought out the fact that siphonic action is produced by the exhaustion of the air within the siphon. With the greater curve of Model 2 prime occured much more rapidly because by the time the water had reached the height at which prime occured Model 2 had less air in the throat and inlet to dissipate and consequently primed much more quickly.

Test no. 3 showed that the effeciency varied but slightly for either model. Plate 3 shows the results of this test.

Acknowledgements:-

The writer wishes to acknowledge the value of the suggestions given by Prof. Franklin Thomas, of the Institute, and Mr. A.L. Sunderegger of Los Angeles.

Also the very valuable information he derived from reading the reports of Mr. R.N. Allen, Mr. G.F. Stickney, and Mr. A.T. Michelson.



3.0
2.0
1.0
Q — cu. ft/sec.
40
50
60
70
EFFECIENCY — %
MODEL I
MODEL II

DATA SHEET # 1

Model 1

Prime

Started		Finish		Diff.
3' 4"	------------	3' 9¼"	----------	5¼"
3' 4¼"	------------	3' 9¼"	----------	5 "
3' 4¼"	------------	3' 9¾"	----------	5½"
3' 5 "	------------	3' 10"	----------	5 "
3' 5¾"	------------	3' 10½"	----------	4¾"
3' 4½"	------------	3' 9 "	----------	4½"
3' 3¾"	------------	3' 10"	----------	6¼"
3' 5 "	------------	3' 9½"	----------	4½"
3' 3¾"	------------	3' 8¼"	----------	4½"
3' 4"	------------	3' 9 "	----------	5 "
3' 4 "	-------------	3' 8½"	----------	4½"

Avg diff. 4.98"

or say 5.00"

DATA SHEET # 2

Model 1

Time to prime after water reached

Trial		Time	Seconds
1	---------------------------	26	"
2	---------------------------	16.5	"
3	---------------------------	25	"
4	---------------------------	18	"
5	---------------------------	22	"
6	---------------------------	21	"
7	---------------------------	24.5	"
8	---------------------------	23	"
9	---------------------------	23.5	"
10	---------------------------	22.5	"
11	---------------------------	25	"

Avg. time 22.6 sec.

DATA SHEET # 3

Model 1

effeciency

Correction factor 5' 2" to be added to tailwater rdg.

Head water rdg	Tailwater rdg	Cor.	Head	Q cu. ft./sec.	Eff. %
3' 8"	4' 0"	9' 2"	5' 6"	1.65	42
3' 8"	4' 0"	9' 2"	5' 6"	2.00	51
3' 8"	4' 0"	9' 2"	5' 6"	2.20	56
3' 8"	4' 2"	9' 4"	5' 8"	2.30	59
3' 9"	4' 2"	9' 4"	5' 7"	2.30	59
3' 9"	4' 0"	9' 2"	5' 5"	2.35	61.5
3' 9"	4' 3"	9' 5"	5' 8"	2.40	61
3' 7"	4' 0"	9' 2"	5' 7"	2.60	66.8
3' 7"	4' 3"	9' 5"	5' 10"	2.70	67.5

DATA SHEET # 4

Model 2

Prime

Started	Finish	Diff.
3' 4"	3' 11"	7"
3' 4"	3' 11½"	7½"
3' 4"	4' 0"	8"
3' 3½"	3' 10½"	7"
3' 4"	3' 11"	7"
3' 4"	3' 11"	7"
3' 3½"	3' 11½"	8"
3' 4"	3' 11½"	7½"
3' 4½"	3' 11½"	7"
3' 3½"	3' 10½"	7"
3' 4½"	3' 10½"	6"

Avg. diff. 7.2"

DATA SHEET # 5

Model 2

Time to prime after water reached

Trial	Time	seconds
1	11½	"
2	9	"
3	11½	"
4	7½	"
5	8½	"
6	11½	"
7	12½	"
8	12	"
9	9½	"
10	8½	"
11	11	"
12	11½	"
13	11½	"

Avg. time 10.5 Sec.

DATA SHEET # 6

Model 2

effeciency

Correction factor 5' 2" to be added to tailwater.

Headwater	Tailwater	Cor.	Head	Q	Eff.
3' 6½"	3' 9"	8' 11"	5' 4½"	1.67	43
3' 6½"	3' 10½"	9' 0½"	5' 6"	1.88	48.5
3' 7¼"	3' 10"	9' 0"	5' 4¾"	2.16	56.5
3' 7¼"	3' 10"	9' 0"	5' 4¾"	2.32	60.5
3' 7¼"	3' 10"	9' 0"	5' 4¾"	2.40	62.5
3' 7¼"	3' 10"	9' 0"	5' 4¾"	2.46	64
3' 9"	4' 0"	9' 2"	5' 5"	2.62	68
3' 9"	4' 1"	9' 3"	5' 6"	2.65	68.5
3' 10"	4' 3"	9' 5"	5' 7"	2.80	70