COMMON ERRORS IN MEASUREMENT OF IRRIGATION WATER

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ABSTRACT

The author discusses errors which occur when dimensions, settings, flow patterns and other factors do not conform to accepted standards for water measurement devices. It is concluded that equipment designed to give accurate measurements may not do so unless due care is exercised in fabrication, installation, operation and maintenance.

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SUMMARY

Devices and structures in general use in the United States for measuring irrigation water are usually subjected to changes in water levels upstream, and perhaps downstream, from the point of measurement. The generally accepted approach to meet this problem is standardization and calibration of the measuring equipment. Use of tables, graphs, or charts developed from the calibration for determining discharge in the field is based on the criteria that the field structure is a replica of the device from which the data were derived and that the flow conditions are identical. Deviations from these standards will result in errors. The magnitude of errors resulting from changes in certain dimensions, incorrect settings, changes in flow patterns, and other deviations is evaluated for some of the commonly used measuring devices. It is concluded that measurements obtained from equipment which is capable of operating with a high degree of accuracy may be subjected to gross errors unless due care is exercised in fabrication, installation, operation, and maintenance.

INTRODUCTION

Many of the measurements of flow made in irrigation systems may not be as accurate as assumed or as would be expected from the type

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of device or structure being employed. In all probability the order of accuracy of the flow measurements derived from the many types of devices used in irrigation systems will show some variation. This deviation will usually be more evident between the different types of structures and methods used but may be apparent when units of the same type are compared.

Some of the reasons for the deviations in accuracy are: (1) principle of operation (that is, volumetric, velocity, or other); (2) degree of exactness to which the flow coefficients have been established (that is, how much study and analysis have been made on the particular device or method); (3) workmanship and the care that is exercised in construction or fabrication and in installation (including the setting); (4) adaptability of the particular device to the existing conditions; (5) proper setting with respect to flow conditions (that is, the approach and exit flow conditions); (6) proper maintenance; (7) cost (in general, better accuracy may be obtained from the more costly devices, although this is not always true); (8) manner of obtaining the final result (that is, whether the rate of flow is determined directly from the device or method, or whether, for instance, head is measured and the end result obtained by calculation or from tables, charts, or curves); (9) means used for obtaining the needed intelligence, for instance, use of a staff gage in the flow, a gage in a stilling well, or a continuous recorder for obtaining head; (10)

care exercised in obtaining the intelligence; and (11) other factors such as extraneous material in the water, range of flows to be covered, etc.

It is not probable that absolute accuracy can be obtained in all instances. However, the reduction of errors to a minimum may be possible if all factors are taken into consideration.

Generally speaking, errors are of two classes: (1) avoidable errors which result from carelessness and can be eliminated by thorough supervision and strict attention to details, and (2) unavoidable errors which are errors of degree; and although possibly they cannot be completely eliminated, they can, by exercise of extreme care and knowledge of their nature and magnitude, be alleviated and satisfactory overall results obtained.

In the United States numerous devices and structures have been developed for the measurement of flows in irrigation systems. Nearly all of these developments are designed to operate in conjunction with separate equipment to control the flows. Only a few of them serve the dual purpose of control and measurement. Except in rare cases, the control is manually operated.

The design of essentially all of the open channel irrigation systems is such that fluctuations of the water levels both upstream and downstream of the measuring device are tolerated. The measuring devices have been developed to accommodate this design procedure.

In effect, any change in water level upstream and, generally, downstream is reflected as a change in discharge through the measuring device.

The generally accepted approach to the solution of the problem of fluctuating water levels is the standardization and calibration of the measuring equipment. The result is a device, which, when built and installed in accordance with the established standards, will pass a range of known discharges for a range of upstream and downstream water levels. The exact instantaneous discharge can be determined by observing the upstream and downstream heads, by means of suitable gages, correctly referenced, and entering charts, graphs, or tables which have been developed by prior calibration of the device under carefully controlled conditions.

Such a procedure assumes that the field installation is a suitable replica of the installation which was calibrated, usually in a hydraulic laboratory. Further assumptions are that conditions of flow, especially in regard to velocity distribution patterns, are similar and that the heads, and other necessary measurements, can be determined with a comparable degree of accuracy.

Since the discharge tables, charts, or graphs are the results of calibrations, they are based on empirical relationships and not on a rational analysis in all instances. Therefore, they are not necessarily susceptible to accurate extrapolation beyond the range of observations from which they were developed.

To obtain accurate measurements of flows in an irrigation system by means of those devices now in general use in the United States, it is therefore necessary to know something of the standards developed and conditions of calibration.

The intent of this discussion is to point out some of the possible errors in measurement which will result from disregard of adherence to close tolerances in the standards developed; from failure to make accurate observations; and from other deficiencies. The examples cited are devices used in open channel irrigation systems. Similar arguments are generally applicable to equipment and structures used in closed conduit systems.

The magnitude of errors introduced in flow measurements by departure from established criteria can be evaluated in many cases. In other instances, errors or inconsistencies are evident but exact evaluation is difficult.

The devices mentioned are not necessarily those most susceptible to errors nor are the cases cited all of those which may cause errors in measurements. Weirs are widely used in the United States for the measurement of irrigation and drainage water, therefore, more attention has been given to possible errors in this device. Since broad crested weirs are not generally used in irrigation measurements, the comments are directed toward sharp crested weirs.

The author is mindful of the general practice on irrigation systems of reading the head gages on measuring devices at intervals, usually once a day. Since an irrigation system rarely reaches regimen flow conditions because of fluctuations in the source of supply, changes in demands, etc., this practice may result in major errors. However, this is a moot question among operators. Until such times as a continuous recorder is developed which will be economically feasible for installation this practice will be followed because it is not practicable to obtain a large number of readings each day at each of the points of measurement. However, the errors pointed out in the following discussion are of such magnitude that they merit careful consideration.

SOURCES OF ERROR

Faulty fabrication or construction. There are numerous possibilities for introduction of errors in flow measurements resulting from faulty construction of measuring devices. The error caused by incorrect dimensions of some of the structures is readily evaluated and may be used as an example to demonstrate the error.

Table 1 shows the discharge error for rectangular or Cippoletti weirs for an incorrect measurement of length of weir crest of only 0.01 foot as compared to the standard which was calibrated and from which the flow formula was derived. Since discharge is directly related to length in the flow equation, an error in length of 0.05 foot would cause the discharge to be in error by five times the values shown in the table for any observed head.

Table 1.--Discharge error for rectangular or Cippoletti weir for an incorrect measurement of length.

The discharge error caused by 0.01-foot error in measurement of the width of the throat of Parshall flumes of standard widths from 1 to 4 feet is shown in Table 2. A constant head of 0.2 foot has been assumed. Also shown in this table is the error introduced by faulty measurement of 0.02 and 0.03 foot. The error is essentially constant for different values of measured head. The flow equation used in development of the table was derived empirically from calibrations.[1]

Table 2.--Discharge error for incorrect measurement of width of Parshall flume.

Similarly, it may be shown that an error in measurement of the width or the breadth of a rectangular submerged orifice will cause considerable error in discharge. Since the discharge is directly related to the area of the orifice, the magnitude of the error is similar to that for the weir, and an error in either length or breadth measurement will be constant for various heads on the orifice or gate.

Error in discharge measurements due to transverse slope of weir crest. When installing Cippoletti and rectangular weirs in the field, it is necessary to set the crest exactly horizontal. If it is

[1]Improving the Distribution of Water to Farmers by Use of the Parshall Measuring Flume, Ralph L. Parshall, Colorado Agricultural Experiment Station, Ft. Collins, Colorado, Bulletin 488, May 1945.

TABLE I
DISCHARGE ERROR FOR RECTANGULAR OR CIPPOLETTI WEIR FOR AN INCORRECT MEASUREMENT OF LENGTH

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

$$Q' = C(L+\Delta L)H^{3/2}$$

$$\frac{Q'}{Q} = \frac{L+\Delta L}{L}$$

$$Q' = \left(\frac{L+\Delta L}{L}\right)Q$$

Error of 0.01 foot in length measurement

WEIR LENGTH L FEET	% ERROR $\frac{Q'-Q \times 100}{Q}$
1.0	1.0
2.0	0.5
3.0	0.33
4.0	0.25

TABLE 2
DISCHARGE ERROR FOR INCORRECT MEASUREMENT OF WIDTH OF PARSHALL FLUME

Equation $Q = 4WH_a^{1.522W^{0.026}}$

W ft.	H_a ft.	Q cfs	Q′ cfs	% ERROR $\frac{Q' - Q}{Q} \times 100$
Error in width measurement of 0.01 foot				
1.0	0.2	0.348	0.351	0.86
2.0	0.2	0.656	0.659	0.45
3.0	0.2	0.972	0.975	0.30
4.0	0.2	1.264	1.267	0.23
Error in width measurement of 0.02 foot				
1.0	0.2	0.348	0.355	2.0
Error in width measurement of 0.03 foot				
1.0	0.2	0.348	0.359	3.1

known that the crest is not level it is common practice to consider the effective head to be the average head on the weir. The error caused by this practice is shown in Figure 1.

Figure 1.--Error in discharge due to transverse slope of Cippoletti weir crest.

Actually, a more precise method is to calculate the discharge using the head at the low end and the head at the high end and average the discharge derived from these two calculations.[2] If this is done, the error is reduced to minor significance.

If it is not known that the weir is inclined and the gage zero is referenced to either the high or the low end, the resulting error is considerably greater. Figure 2 shows the magnitude of the error in discharge resulting from measurement of head at either end of 12-, 24-, 36-, and 48-inch Cippoletti weirs having a transverse slope of 0.01 instead of using the average head over the weir. An inclination of about 6° will cause an error in the order of 1 percent. An angle of this magnitude should be detected by eye and corrective measures taken.

Figure 2.--Error in discharge for head measured at end of Cippoletti weir instead of average head.

[2]Error in Discharge Measurements Due to Transverse Slope of Weir Crest, Warren E. Wilson, Civil Engineering, Vol 9, No. 7, p 429, July 1939.

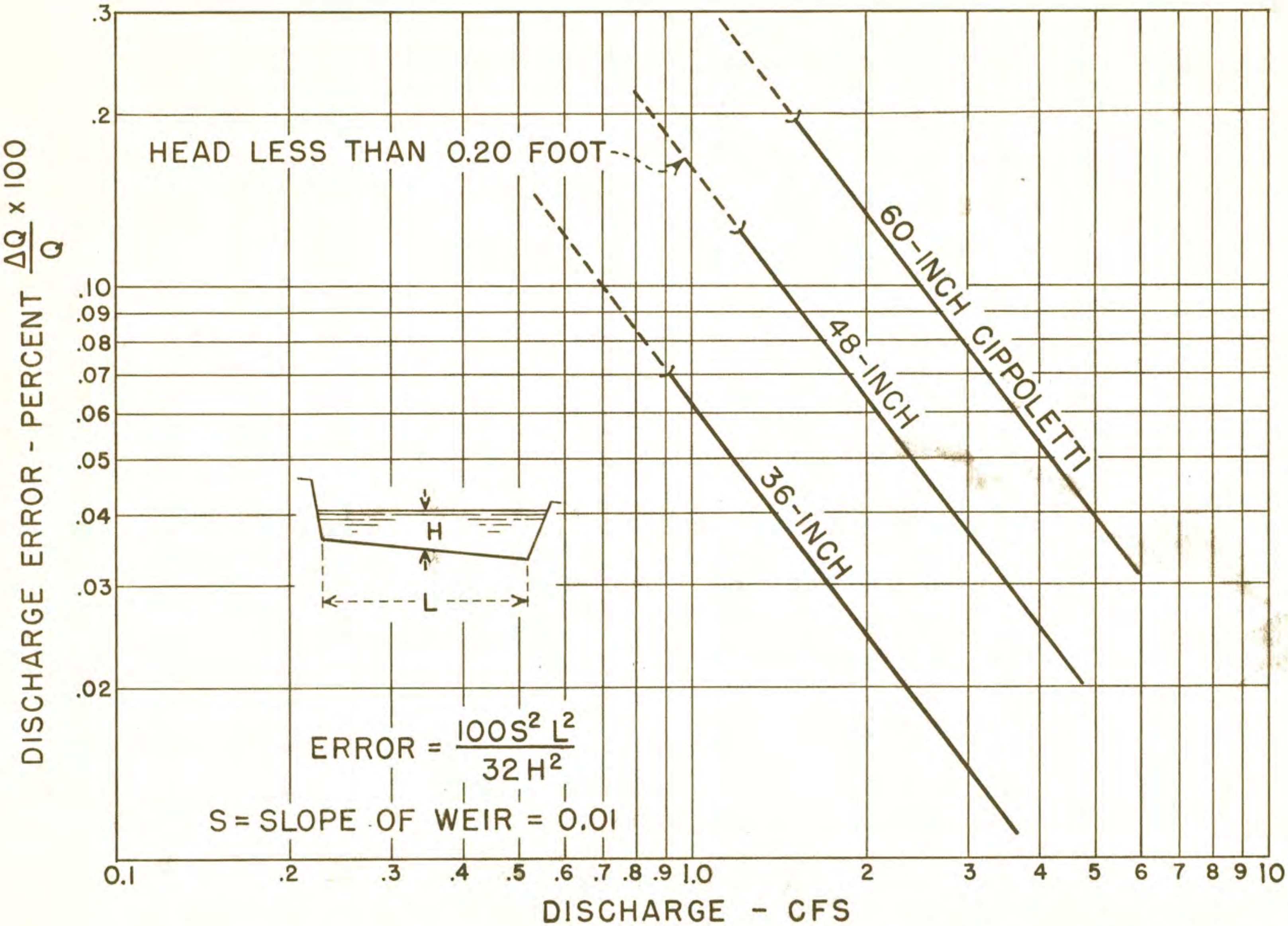

FIGURE 1 - ERROR IN DISCHARGE DUE TO TRANSVERSE SLOPE OF CIPPOLETTI WEIR CREST

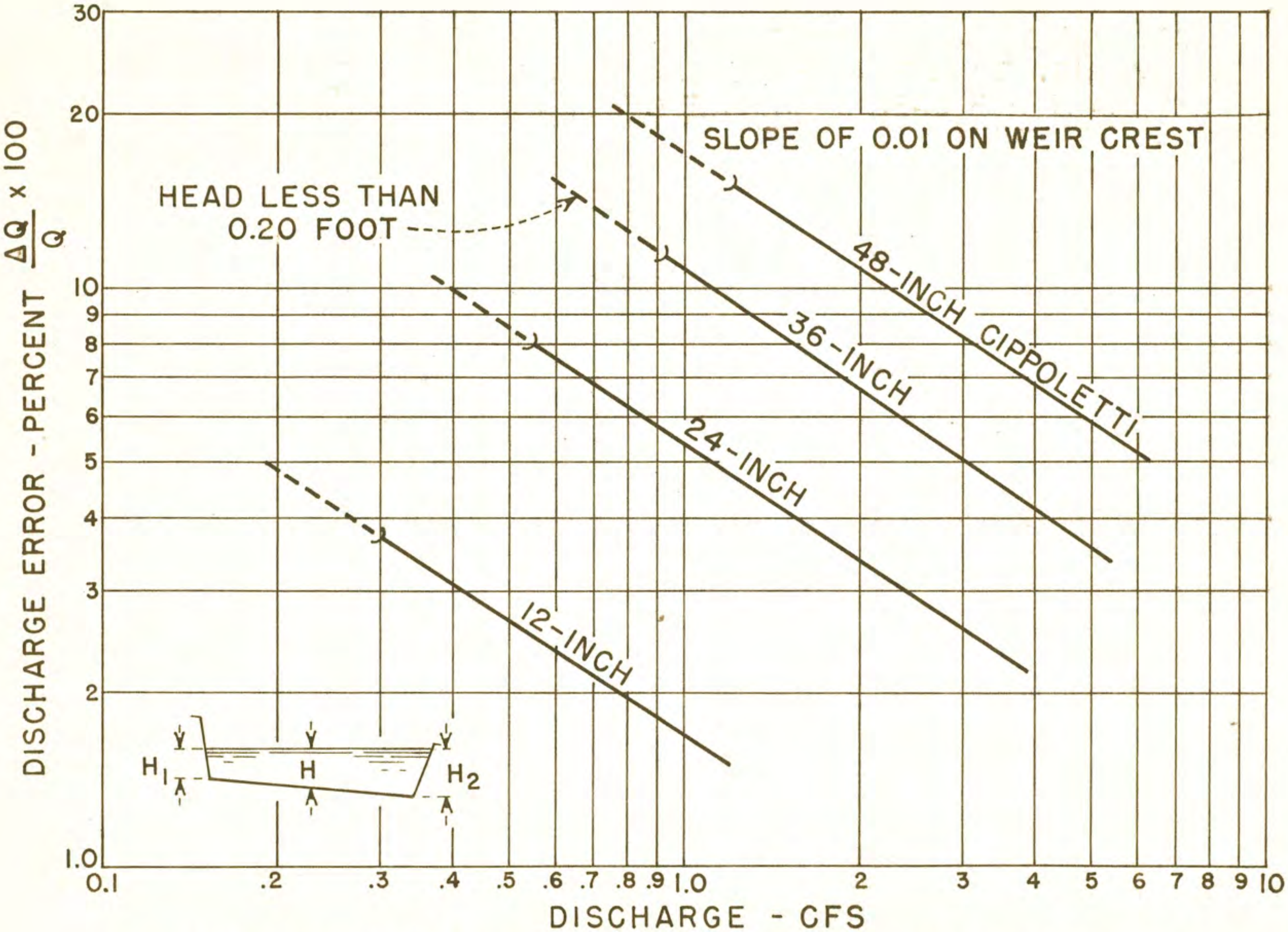

FIGURE 2-ERROR IN DISCHARGE FOR HEAD MEASURED AT END OF CIPPOLETTI WEIR INSTEAD OF AVERAGE HEAD

Error in discharge resulting from errors in reading the head. Perhaps the most common error in measuring irrigation water is to misread the head. This may result from incorrect location of the gage, or because the head gage is dirty, a stilling well is not used, and there is considerable fluctuation of the water surface, or carelessness on the part of the reader in not obtaining a good average reading at the time the gage is observed.

Figure 3 shows the error in discharge resulting from a 0.01 foot incorrect head reading on 12- to 48-inch Cippoletti and 90° V-notch weirs. This figure clearly illustrates that even with a small error of 0.01 foot, an error of approximately 7-1/2 percent in discharge results when the lower heads are being measured. For greater heads, the error is less. Also, it can be noted that for the longer weirs this slight error in head reading results in quite large errors in discharge measurements.

Figure 3.--Discharge error for 0.01 foot incorrect head reading on weirs.

As in the case of weirs, the head at the throat of a Parshall flume is quite easily misread in the field. Figure 4 shows the error in discharge measurements resulting from a misreading of the gage of only 0.01 of a foot. Parshall flumes of throat widths of from 6 to 36 inches are shown on this figure. It can be noted that the error,

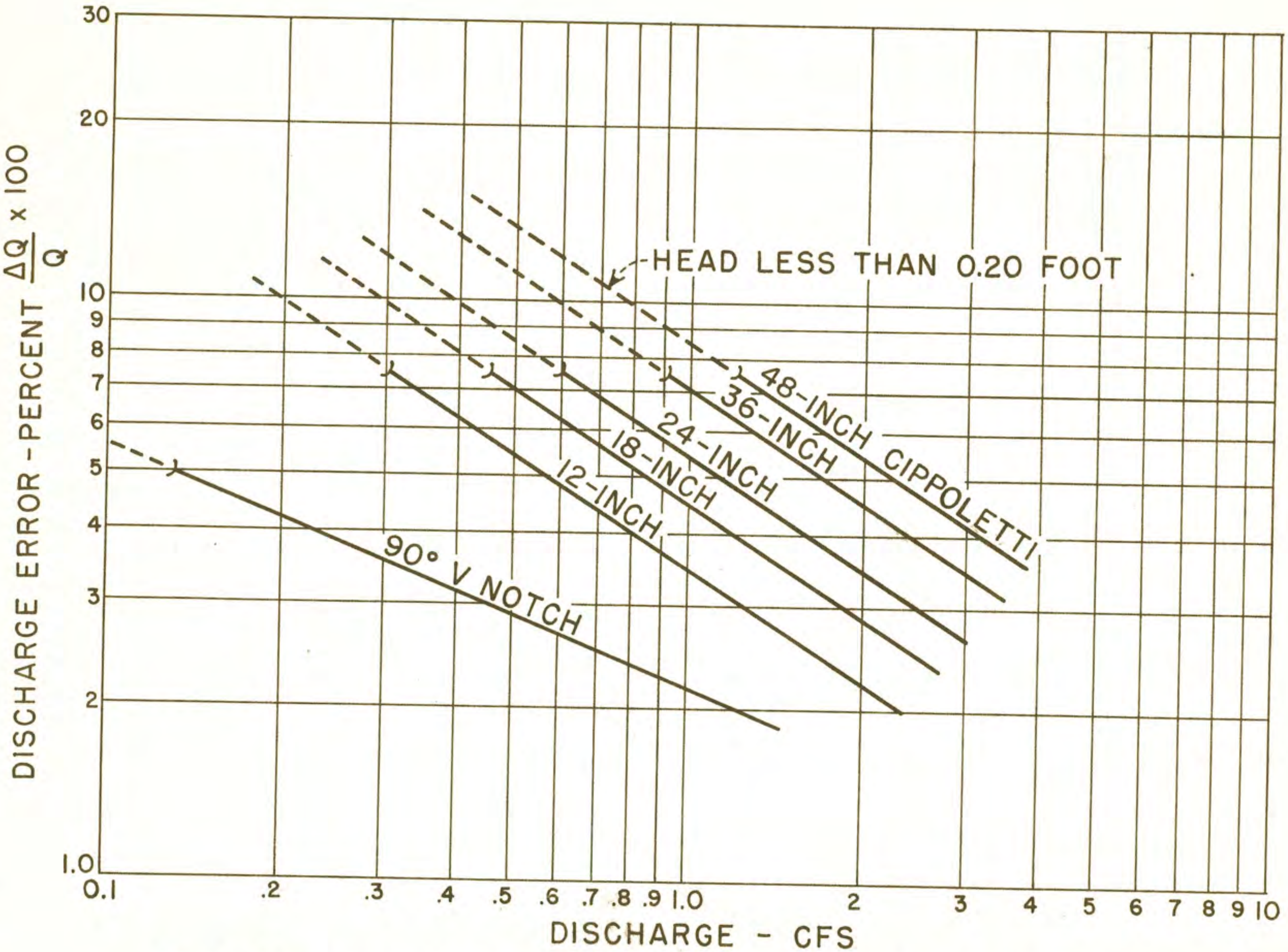

FIGURE 3 - DISCHARGE ERROR FOR 0.01-FOOT INCORRECT HEAD READING ON WEIRS

in general, is approximately the same as for misreading the head an equal amount when weirs are considered.

Figure 4.--Discharge error for 0.01 foot incorrect head reading on Parshall flumes.

Figure 5 shows the error in measurement resulting from an error of 0.01 foot in reading of the head on an 8-, 12-, and 18-inch meter gate and an 18-inch screw-lift gate. The meter gate has a circular leaf and the screw-lift gate has a rectangular leaf. Included on Figure 5 is the error caused by 0.01 foot incorrect head reading for the constant-head orifice turnout.[3] It should be noted that the percentage error in discharge resulting from misreading the head on an orifice is in general less than the same misreading on a weir.

Figure 5.--Discharge error for 0.01 foot incorrect head reading on gates.

Error in discharge measurement caused by incorrect zero setting. The error for incorrect zero setting of the head gage is of the same magnitude as the error for misreading the head an equal amount. Improper positioning of the gage used to read the head is probably the most common error found. In the field it is difficult to reference the

[3]Water Measurement Manual, United States Department of the Interior, Bureau of Reclamation, First Edition, Denver, Colorado, May 1953, p 77.

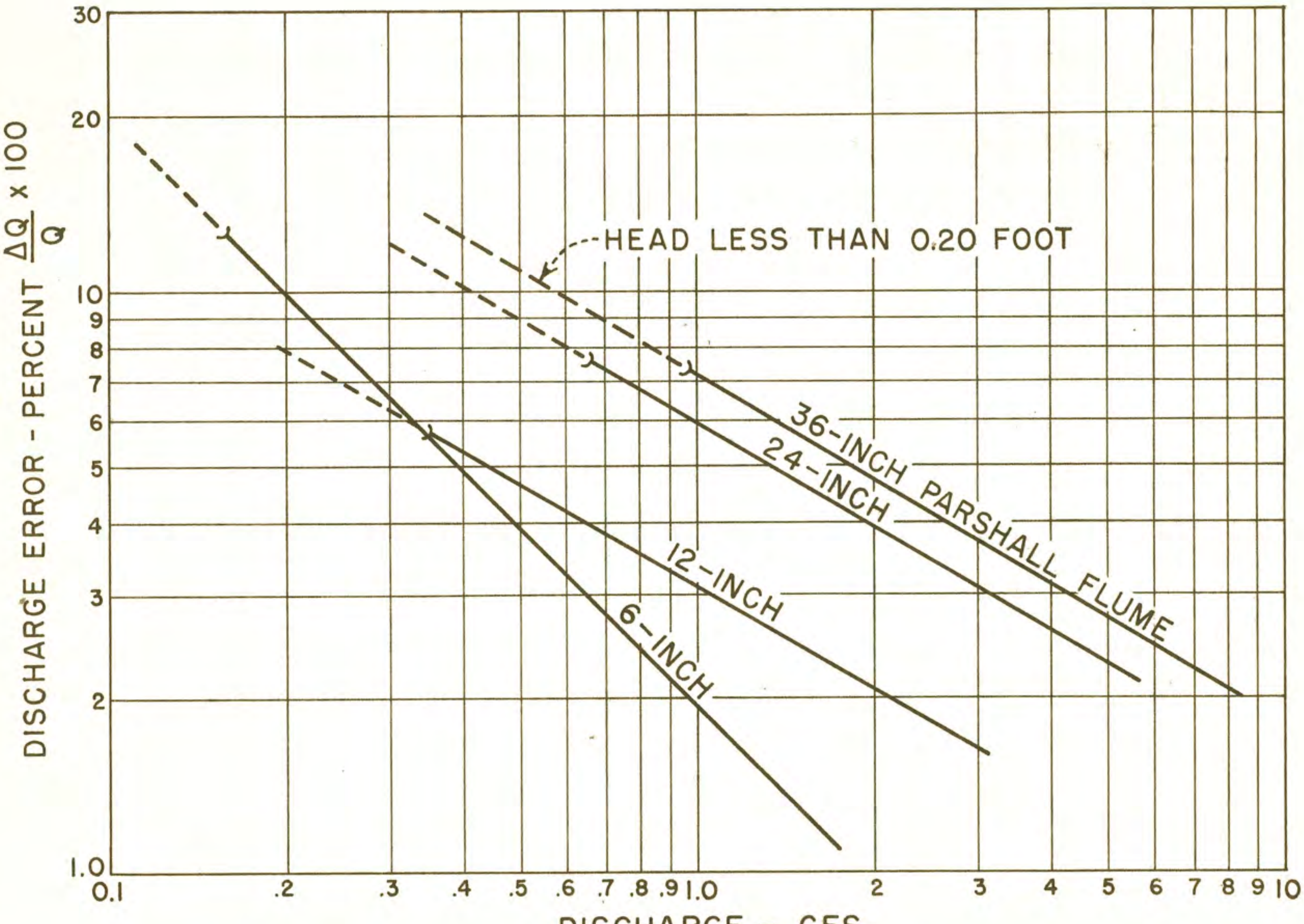

FIGURE 4 - DISCHARGE ERROR FOR 0.01-FOOT INCORRECT HEAD READING ON PARSHALL FLUMES

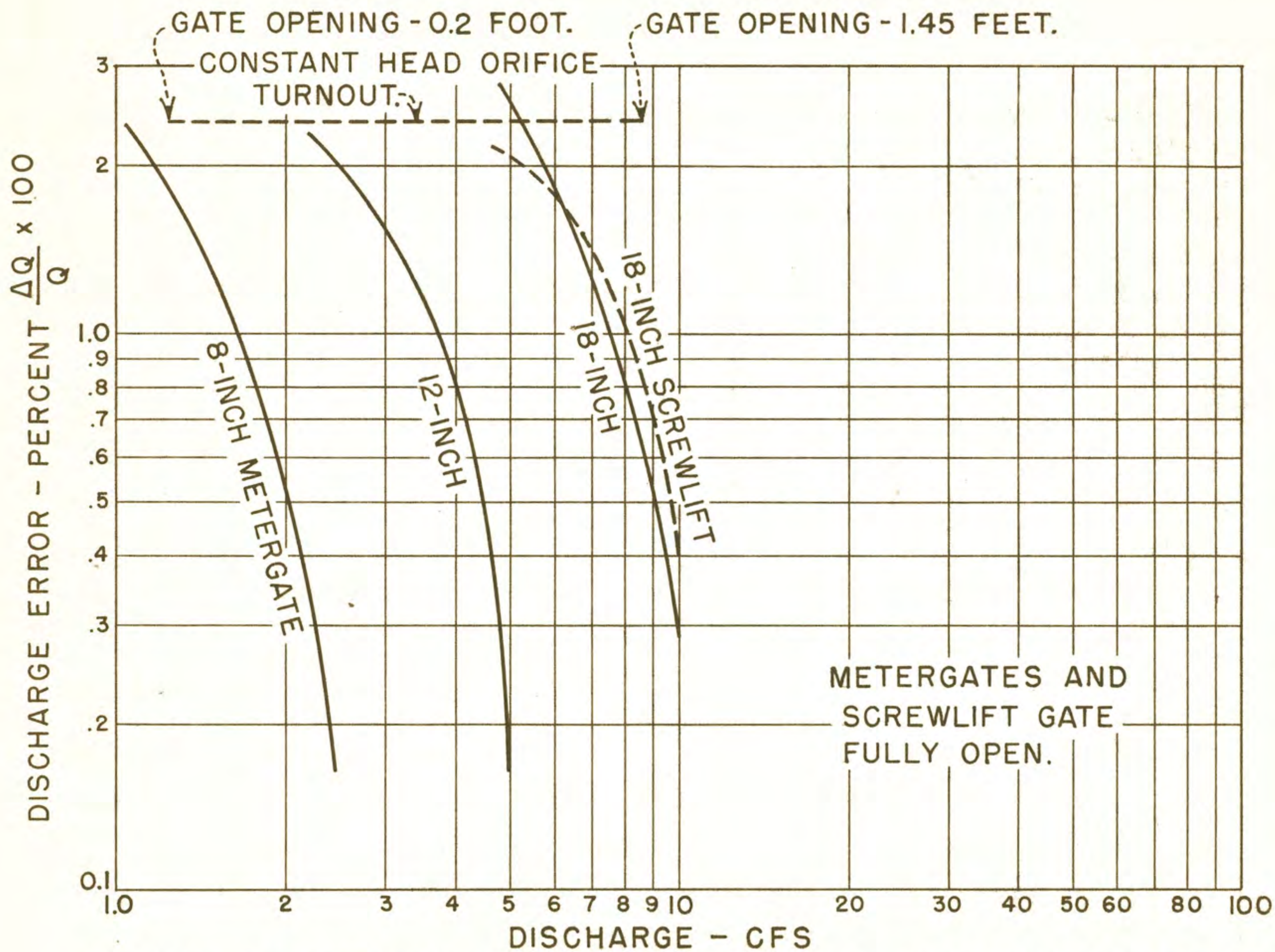

FIGURE 5 - DISCHARGE ERROR FOR 0.01 - FOOT INCORRECT HEAD READING ON GATES

exact zero of the gage to the crest of a weir, a submerged orifice, or to a turnout gate. Extreme care should be exercised in setting the gages since incorrect settings cause errors at all flows, Figures 3, 4, and 5.

Errors resulting from improper gage location. Proper location of the gage for obtaining head on measuring devices is important if errors are to be avoided. In most instances flow relationships have been determined empirically with a particular type of gaging device placed in a specific location. Hence, there is included in the overall calibration a secondary effect of calibration of the gaging system employed to obtain head. Because of changes in the flow pattern of the stream as it passes through the measuring section, minor deviations from the standard in gage design and location may appreciably affect the quality of the measurements.

In the case of a weir, there is a downward curve of the water surface as the flow passes through the notch. This curved surface, or drawdown, extends some distance upstream. The exact distance is dependent upon local conditions. The head of the weir must be measured beyond the effect of the drawdown. In the development of the basic weir formulas, the head was observed at distances upstream from the weir notch varying from about 4 to 9 times the maximum head over the weir. Therefore, many authorities have accepted a minimum distance of four times the maximum head to be measured. However, King[4] says the distance should be at least 2.5 times the maximum head. Experiments have shown that there is some effect of drawdown to a distance upstream of some six times the head on the weir.[5,6] However, the influence at this distance is minor. Within the practical limits of the gages used at weir installations in irrigation systems, it appears that a distance upstream of four times the maximum head is quite adequate providing other criteria such as height of weir, width of weir pool, etc., are complied with.

Unpublished results of brief studies conducted in the Hydraulic Laboratory of the Bureau of Reclamation show that it is extremely difficult to detect differences of head on enameled staff gages located 2, 4, and 10 times the head on the weir. These same studies did show that positioning the enameled staff gage on the weir bulkhead, a practice sometimes followed in irrigation measurements, Figure 6, may result in errors. Certain positions on the bulkhead, with respect to the weir notch, gave a higher reading for certain flows than a gage correctly positioned. At other flows the reading was less. As the gage on the bulkhead was moved away from the weir

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[4]Handbook of Hydraulics, H. W. King, Third Edition, p 91, McGraw-Hill Book Company, Incorporated, New York City, 1939.

[5]Flow of Water Over Weirs, Fteley and Stearns, Transactions, ASCE, Vol 12, 1883.

[6]Verification of the Bazin Weir Formula by Hydrochemical Gagings, F. A. Nagler, Transactions, ASCE, Vol 83, 1919.

notch more consistent results were evident. It was found, for the flow conditions tested, that when the gage was placed on the weir bulkhead at a minimum distance of twice the maximum recommended head for the weir, the difference in the heads read on this gage and one correctly placed upstream was within the limits of visual observation.

Figure 6.--Enameled gage for observing head on weir fastened to weir bulkhead too close to weir notch.

When the velocity of approach is high and the irrigation channel has a high loss coefficient, there is a danger of placing the gage so far upstream from the weir crest that an error will prevail unless a correction is made for the loss of head due to channel friction between the point of measurement and the weir.

Errors in measurement can easily occur if the gages used in a Parshall flume are not placed in the manner and location developed in the standards. The ratings for this flume include a calibration of the gage positions. The gages are located in drawdown areas. Under these conditions, movement of the gage upstream or downstream from the standardized location will change the head reading and an error in discharge will result. For similar reasons, if a stilling well is used, the type and location of the entrance to the wells should be as specified. Substantial errors in field measurements have been traced to changes in location or design of the still well entrances.


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Similar remarks apply to the location of the two gages used in the constant-head orifice turnout. The discharge tables developed from the calibration of this device are accurate only if the gages are placed in the locations given in the standard drawings.

Discharge errors due to neglecting velocity of approach to a weir. In practical application the cross sectional area of the approach channel can usually be made sufficiently large in comparison with the weir notch to render the effect of velocity of approach negligible. If, however, the approach velocity is not maintained at or below 0.5 foot per second, it must be taken into account and a correction applied.[3] In other words, if the normally used equations, charts, or tables are used, without correction, for obtaining discharge from measured head an error will result.

In irrigation practice the velocity of approach to a weir is usually increased over that for which it was originally designed by: (1) a general restriction of the cross sectional area of the weir pool by deposits of vegetal growth, or (2) sediment or other accumulations in the bottom of the weir pool. Either will change the standards to which the weir installation should conform.

A general reduction of the cross sectional area of the weir pool will cause an increase in approach velocity which is directly related to the degree of restriction. The percentage error for a range of approach velocities and heads over weirs, except the V-notch type, is given in Table 3. The error is such that the discharge is actually greater than that obtained from the discharge tables by the percentages given in Table 3.

Table 3.--Discharge error resulting from failure to correct for velocity of approach.

Authorities agree that the crest of the weir should be a distance not less than two times the depth of water over the crest above the bottom of the approach channel for accurate results. A greater height of weir crest is to be preferred when practicable. A weir installed in an irrigation channel in accordance with this standard may retain its accuracy for only a short period because of reduction of depth of the weir pool by sediment deposits, Figure 6. The regularly used tables will no longer apply. The error may be reduced or possibly eliminated by use of Rehbock's formula for computing discharge from the head observations.

Table 4 gives the percentage error in discharge that will occur if regular weir tables are used instead of correcting for the reduced height of weir by use of the Rehbock formula. The table is divided into two parts: The first part shows a constant head of 0.2 foot over a weir. The value of the ratio of H over P is varied and the error shown. The second part of the table is calculated for a constant

TABLE 3
DISCHARGE ERROR RESULTING FROM FAILURE TO CORRECT FOR VELOCITY OF APPROACH

Velocity of Approach ft./sec.	Observed Head Over Weir-Feet				
	0.2	0.4	0.6	0.8	1.0
	(Error in per cent)				
0.5	2.7	1.3	0.9	0.6	0.6
1.0	9.8	5.1	3.4	2.7	2.2
1.5	20.8	10.9	7.5	5.7	4.7
2.0	33.5	18.1	12.6	9.7	7.9
2.5	48.0	26.6	18.7	14.5	11.9
3.0	63.7	36.1	25.6	19.9	16.5

head of 0.5 foot and is handled in a manner similar to the first part of the table.

Table 4.--Error in discharge for changes in height of weir.

This error is introduced in the field by improper maintenance and cleaning of the weir pool. As the pool fills the ratio of H over P increases and the error increases.

Numerous instances have been noted in the field where weirs have been placed in channels having relatively high gradients. It is very difficult to hold a properly proportioned weir pool under these conditions and obtain smooth flow through the weir notch. Obviously, the increased velocity of approach and turbulence will cause errors in measurement. Channel curvature and consequent poor velocity distribution over the weir crest will also cause excessive errors which are not easily evaluated. Laboratory experiments have shown that the extreme difference in discharge over a weir for a constant head, but with the upstream velocity distribution varied, amounted to 26 percent.[7] A weir with very poor approach conditions is shown in Figure 7.

Figure 7.--Weir with very poor approach conditions.

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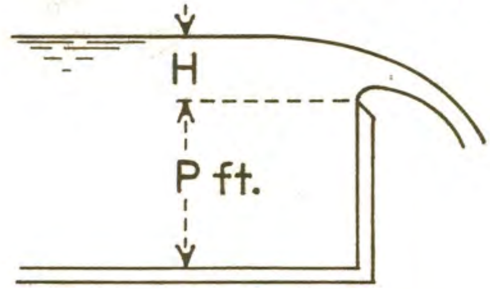
[7]Precise Weir Measurements, by Ernest W. Schoder and Kenneth B. Turner, Transactions, ASCE, Vol 93, 1929, p 999.

TABLE 4
ERROR IN DISCHARGE FOR CHANGES IN HEIGHT OF WEIR

Rehbock formula for rectangular sharp crested weir

$$Q = \frac{2}{3}\sqrt{2g}\,LH^{3/2}\left(0.605 + \frac{1}{320H-3} + 0.08\frac{H}{P}\right)$$

$$Q = KLH^{3/2}; \quad K = 3.235 + \frac{1}{60H-0.56} + 0.428\frac{H}{P}$$



WEIR HEIGHT P	$\frac{H}{P}$	COEFFICIENT K	% ERROR $\frac{K-K_\infty}{K_\infty} \times 100$
Head = 0.2 foot			
0.5	0.4	3.49	5.6
1.0	0.2	3.41	2.7
2.0	0.1	3.37	1.5
3.0	0.07	3.35	0.9
∞	0	3.32	0
Head = 0.5 foot			
0.5	1.0	3.70	13.1
1.0	0.5	3.48	6.4
2.0	0.25	3.38	3.4
3.0	0.17	3.34	2.1
∞	0	3.27	0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Discharge error due to turbulence and surges. Turbulence and surges occur in approach channels to weirs and other types of measuring devices. The cause is usually high velocity of approach but may be from gates or valves, sudden changes in section, or others. Such disturbances are usually evidenced by erratic results in measurements. The disturbances on the surface rarely follow a true sine wave pattern. Hence, an average reading of the head may cause appreciable error. Since the pattern is very complex, corrections are not readily applied to the calculations. Corrective measures to quiet the flow provide the best solution. This may not be an easy task.

Weir blade sloping upstream or downstream. In constructing a weir, it is necessary to have the plane of the upstream face of the weir vertical if accurate measurements are to be obtained. Experiments with sloping weirs show that the coefficient changes if the weir blade is tilted in an upstream or downstream direction; that is, when the face of the weir blade is not plumb. This change is slight, and the weir face may be out of plumb a few degrees before the accuracy of the measurement is seriously affected.[8]

Roughness of upstream face of weir and bulkhead. For consistent and accurate flow measurements the upstream face of the bulkhead and weir blade must be smooth. Offsets, protruding bolt heads, and surface

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[8]Boulder Canyon Project Final Reports, Part IV, Hydraulic Investigations, Bulletin 3, Studies of Crests for Overfall Dams, United States Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1948.

roughness must be avoided upon installation. Maintenance is necessary to retain a smooth surface. Sufficient work has not been done to provide an exact evaluation of the errors resulting from the many possible kinds of roughness. It was found from one series of experiments[7] that "the percentage increase in discharge due to changing the roughness of the upstream face of the weir bulkhead from that of a polished brass plate to that of a coarse file for a distance of 12 inches below the crest is shown to range from about 2 percent for 0.50-foot head to about 1 percent for 1.35-foot head." Nagler's[9] experiments showed that when the upstream face of the weir was roughened, to the crest, with coarse sand (retained on No. 8 standard sieve and passing No. 4) that the increase in discharge ranged from 6.5 percent at a 0.2-foot head to 4.7 percent for a 0.5-foot head. The larger projections caused by the addition of nuts and pieces of metal on the bulkhead below the crest in Nagler's experiment caused about the same increase in discharge.

Rounding of sharp edge at crest of weir. In irrigation practice many of the older weirs were constructed of wood. In this type of construction the original sharp edge of the crest soon becomes rounded. Rust and corrosion also produce a rounding effect on metal weir blades. The effect of this rounding is to cause an increase in

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[9] Floyd A. Nagler, Discussion to Precise Weir Measurements, Transactions, ASCE, Vol 93, 1929, p 1115.

the flow rate for a given head when compared to a sharp crested weir. Considerable experimentation has been done to evaluate the effect of the rounding of the crest. The results show that the percentage increase in discharge due to the rounding decreases as the head increases. For a head of 0.5 foot, an increase of some 2, 3, 5-1/2, 11, and 13-1/2 percent may be expected for roundings having radii of 1/24, 1/8, 1/4, 1/2, and 3/4 inch, respectively. There is a deficiency of data for the higher heads with the longer radius roundings. However, with radii smaller than those given above, the increases become consistently smaller as the head increases. As an example, the increase in discharge of 2 percent, given above for the 1/24-inch rounding at 0.5-foot head, becomes 0.7 percent at 1.0-foot head and about 0.5 percent at 1.35-foot head. An extreme example of rounding of a weir crest is shown in Figure 8.

Figure 8.--Weir on which the crest has become appreciably rounded.

Submergence of weirs. For the measurement of irrigation water it is not the usual practice to install weirs where submergence is anticipated. However, changes in the regimen of the channel downstream may cause a weir to operate under submerged conditions. Submerged flow, at its best, is relatively unstable. Therefore, the results of the studies of submerged weirs are not in good agreement and it may be concluded that measurements made by a submerged weir


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should be considered as approximate only.[3,4] One solution is to remove the cause of submergence from the downstream channel if this is practicable.

Aeration of the downstream nappe of a weir. One of the general conditions for accurate and consistent measurements by contracted weirs is that air circulates freely on all sides of the flow issuing from the weir notch. Such conditions ordinarily are not difficult to obtain. The weir bulkhead in irrigation structures is constructed of concrete in many instances. The use of metal weir blades which do not project a sufficient distance from the concrete, or an improper bevel of the concrete downstream from the blades can easily restrict the desired air circulation. The effect of this restriction of air is to increase the flow rate for a given head. The increase in discharge will depend on the degree of restriction of air and can be appreciable.

The problem is more pronounced when suppressed weirs are used. For standard suppressed rectangular weirs used in irrigation practice, the sidewalls are generally carried straight through the structure. Thus, auxiliary means must be provided to supply air to the underside of the nappe. Unless adequate air is provided to this area to replace that carried away by the jet, a partial vacuum will be formed. The result is a lowering of the nappe and an increase in discharge over that obtained with adequate aeration. A condition of instability may also exist in which case erratic measurements would be obtained. Johnson[10] found that the discharge would be increased about 3-1/2 percent at 0.5-foot head and about 2 percent at 1.0-foot head when the pressure under the nappe was reduced only 0.8 inch of water below atmospheric. When the pressure was further reduced to 1.2 inches of water, below atmospheric, the increase in discharge was about 5 percent and 2-3/4 percent for heads of 0.5 and 1.0 foot, respectively. The size of vents adequate to relieve this negative pressure will depend on conditions at the weir. Both Johnson[10] and Howe[11] have developed solutions for calculating the size of vents. The important consideration is to design the vents of adequate proportions to relieve the low pressure insofar as is possible.

Other factors which affect the accuracy of discharge measurements over weirs. There are factors, other than those covered separately above, which may cause errors in discharge measurements made with weirs. Many of them apply equally as well to other types of structures and devices.

Obstructions in the measuring section cause errors proportionate to the magnitude of such an obstruction. In irrigation systems floating detritus, weeds, moss, etc., may obstruct the water passage, Figure 9. Frequent and close inspection accompanied by remedial measures will relieve this condition.

Figure 9.--Obstruction in weir notch--silt and vegetation in weir pool.

[10] The Aeration of Sharp Crested Weirs, by Joe W. Johnson, Civil Engineering, March 1935, Vol 5, No. 3, p 177.

[11] Aeration Demand of a Weir Calculated, by J. W. Howe, C. C. Shieh, and Arturo Obadia, Civil Engineering, May 1955, p 59.

Fig. 9

Changes in viscosity and surface tension of the fluid are known to alter the flow coefficient. However, the effect of these two factors is considered negligible in irrigation systems where the flow media is water, and wide variations of temperature are not encountered and, further, provided that the restrictions on high and low heads over the weir are complied with.

At very low heads, flow over a weir may become quite unstable and errors and inconsistencies in the measurements will result. Because of viscous drag and the tendency of the nappe to adhere to weir crest there is general agreement among experimenters that heads of less than 0.2 foot will not produce reliable results when the usual discharge tables or formulas are used.

The results of many experiments on weirs show that the formulas developed for rectangular weirs do not hold when the head exceeds about one-third of the length. There are indications that the discharge formula for the Cippoletti weir, in lengths over 1 foot, is slightly in error at heads less than one-third the length.[12] Possibly the rule should be that the head should not exceed one-fourth of the length if errors are to be reduced to a minimum.

As previously stated the flow formulas for weirs have been developed empirically and are not necessarily susceptible to extrapolation. Most of the data have been derived for heads up to 2.0 feet.

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[12] The Discharge of Three Commercial Cippoletti Weirs, R. B. Van Horn, Eng. Exp. Sta. Series Bulletin No. 85, University of Washington, Seattle, Washington, November 1935.

Although some data are available for higher heads, authorities generally agree that a 2.0-foot head should not be exceeded for any length weir if good quality results are desired.

It has been previously pointed out that the percentage of error in discharge resulting from a given error in measuring the head will decrease as the head increases. Therefore, the minimum error and, hence, the greater accuracy can be expected if the discharge occurs under the maximum head commensurate with the above limitations.

Careful visual inspections made at regular intervals will remove many of the sources of error mentioned above. These inspections should also disclose other sources of errors such as leaks around the measuring structure, through weir bulkheads, or from drains in the structure.

CONCLUSIONS

The charts, tables, and discussions presented in this paper are not intended to point out all the possible errors in all of the devices and structures used in measuring irrigation water. However, from the examples cited, the following conclusions may be drawn.

To obtain accurate measurements of irrigation water it is necessary to make a careful study for the selection of a proper device to fit the conditions pertaining at the site. Even with careful planning and selection of an excellent primary measuring device, it is probable that errors may be introduced into the measurements unless due care is exercised in fabrication, installation, operation, and proper maintenance of the devices or structures. The magnitude of these errors can be appreciable and the value of a well planned measuring program may be reduced considerably by failure to anticipate and remove the cause of the errors.

The possible errors cited are both negative and positive and may tend to cancel each other. However, more careful scrutiny shows, especially in the case of weirs, that the probability is that there is a predominance of negative errors. This means then that usually more water is being delivered than is apparent from the measurements.

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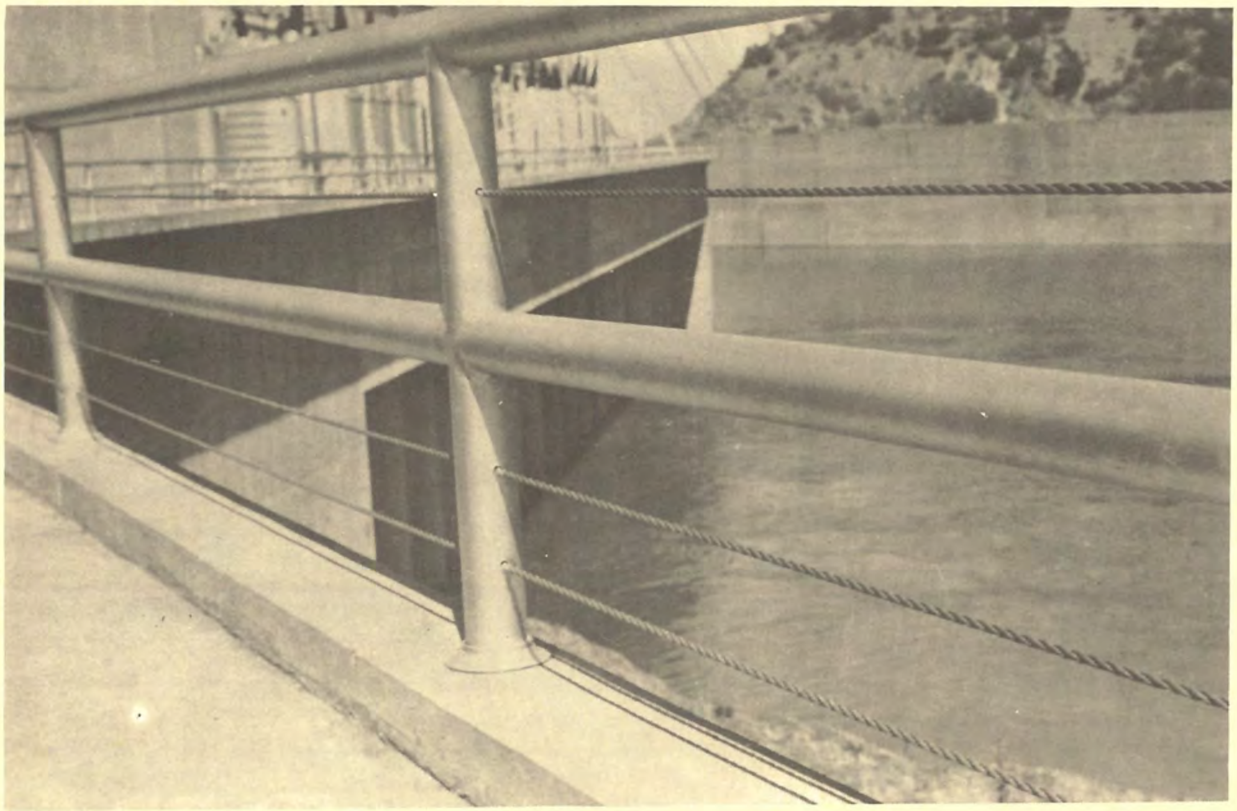
Department of the Interior

Bureau of Reclamation

OPERATION AND MAINTENANCE EQUIPMENT AND PROCEDURES

RELEASE NO. 23

January, February and March 1958



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OPERATION AND MAINTENANCE

EQUIPMENT AND PROCEDURES

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INTRODUCTION

In order to insure proper recognition to those individuals whose suggestions are published in this and subsequent bulletins, the suggestion number as well as the person's name will be shown. All offices are also reminded to notify their Suggestion Awards Committee when a suggestion is adopted for Bureau operation.

This bulletin, published quarterly, is circulated for the benefit of irrigation project operation and maintenance people. Its principal purpose is to serve as a medium of exchanging operation and maintenance information. Reference to a trade name does not constitute the endorsement of a particular product, and omission of any commercially available item does not imply discrimination against any manufacturer. It is hoped that the labor-saving devices or less costly equipment developed by the resourceful water users will be a step toward commercial development of equipment for use on irrigation projects in a continued effort to reduce costs and increase operating efficiency.

* * * * *

Division of Irrigation Operations
Commissioner's Office
Denver, Colorado

COMMON ERRORS IN WATER MEASUREMENT

Many of the measurements made of water flowing in our irrigation system may not be as accurate as assumed or as would be expected from the type of device or structure being employed. It is probable that absolute accuracy cannot be obtained in the measurement of water in all instances. However, the reduction of errors to a minimum may be possible if all factors are taken into consideration.

Some of the reasons for errors and deviations in water measurement are discussed in this article adapted for the Bulletin from a paper presented by Mr. C. W. Thomas, Hydraulic Engineer, Bureau of Reclamation, Denver, Colorado at a meeting in Denver of the ASCE Irrigation and Drainage Division, September 8-10, 1955. The paper, published in the Journal of the Irrigation and Drainage Division of the American Society of Civil Engineers as Paper 1362, September 1957, "Common Errors in Measurement of Irrigation Water," is available and includes references to the source of data used in the analyses. For the sake of brevity, these are omitted in this article. However, some equations used by Mr. Thomas in the discussions herein are given as notes at the end of this article.

The design of essentially all of the open channel irrigation systems is such that fluctuations of the water levels both upstream and downstream of the measuring device are tolerated. The measuring devices have been developed to accommodate this design procedure. In effect, any change in water level upstream is reflected as a change in discharge through the measuring device. When the device is submerged, changes in downstream levels also affect the discharge.

The generally accepted approach to the solution of the problem of fluctuating water levels is the standardization and calibration of the measuring equipment. The result is a device, which, when built and installed in accordance with the established standards, will pass a range of known discharges for a range of upstream and downstream water levels. The exact instantaneous discharge can be determined by observing the upstream and downstream heads, by means of suitable gages, correctly referenced, and entering charts, graphs, or tables which have been developed by prior calibration of the device under carefully controlled conditions.

Such a procedure assumes that the field installation is a suitable replica of the installation which was calibrated, usually in a hydraulic laboratory. Further assumptions are that conditions of flow, especially in regard to velocity distribution patterns, are similar and that the heads, and other necessary measurements, can be determined with a comparable degree of accuracy.

Since the discharge tables, charts, or graphs are the results of calibrations, they are based on empirical relationships and not on a rational analysis in all instances. Therefore, they are not necessarily susceptible to accurate extrapolation beyond the range of observations from which they were developed.

Mr. Thomas concludes in his article that equipment designed to give accurate measurements may not do so unless due care is exercised in fabrication, installation, operation and maintenance; that absolute accuracy may be unattainable, but the reduction of errors is possible.

Two Classes of Errors

Errors in water measurement may be considered of two classes: (1) avoidable errors which result from carelessness and can be eliminated by thorough supervision and strict attention to details, and (2) unavoidable errors which are errors of degree; and although possibly not of a type that can be eliminated entirely, they can, by use of extreme care and a knowledge of their nature and magnitude, be alleviated and satisfactory overall results can be obtained.

Faulty Fabrication or Construction

There are numerous possibilities for introduction of errors in flow measurements resulting from faulty construction of measuring devices. The error caused by incorrect dimensions of some of the structures is readily evaluated and may be used as an example to demonstrate the error.

TABLE I

Discharge Error for each 0.01-foot error in length.

Weir Length (feet)	Discharge Error Percent
1.0	1.0
2.0	0.5
3.0	0.33
4.0	0.25

Table I shows the discharge error for rectangular or Cippoletti weirs for an incorrect measurement of length of the weir crest of only 0.01 foot compared to the standard which was calibrated and from which the flow formula was derived. Since discharge is directly related to length in the flow equation, (Equation "A" in notes), an error in length of 0.05 foot would cause the discharge to be in error by five times the values shown in the table for any observed head.

TABLE II

Discharge Error for incorrect measurement of width of Parshall flume.

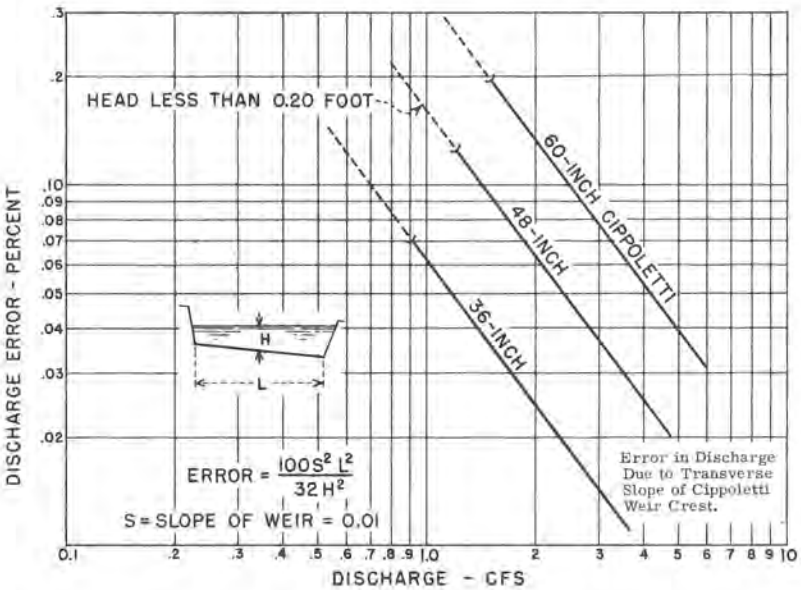
Width (ft.)	Discharge Error - Percent for width error of 0.01 ft.	0.02 ft.	0.03 ft.
1.0	0.86	2.0	3.1
2.0	0.45	--	--
3.0	0.30	--	--
4.0	0.23	--	--

The discharge error caused by 0.01-foot error in measurement of the width of the throat of Parshall flumes of standard widths from 1 to 4 feet is shown in Table II. A constant head of 0.2 feet has been assumed. Also shown in this table is the error introduced by faulty measurements of 0.02 and 0.03 feet. The error is essentially constant for different values of measured head. Flow equation "B", used in development of the table, is given in the notes.

Similarly, it may be shown that an error in measurement of the width or the breadth of a rectangular submerged orifice will cause considerable error in discharge. Since the discharge is directly related to the area of the orifice, the magnitude of the error is similar to that for the weir, and an error in either length or breadth measurement will be constant for various heads on the orifice or gate.

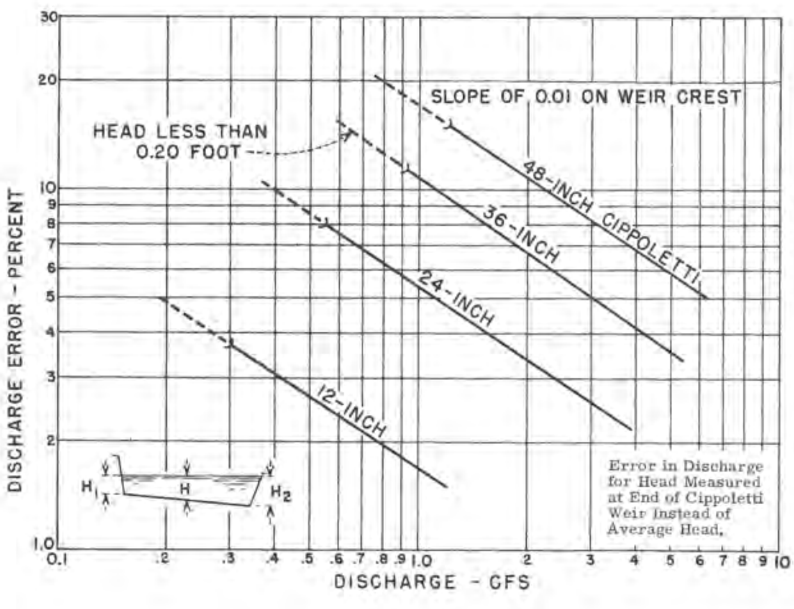
Error in Discharge Measurements Due to Transverse Slope of Weir Crest

When installing Cippoletti and rectangular weirs in the field, it is necessary to set the crest exactly horizontal. If it is known that the crest is not level, it is common practice to consider the effective head to be the average head on the weir. The error caused by this practice is shown in the figure at upper left.



Error in Discharge Due to Transverse Slope of Cippoletti Weir Crest.

Actually, a more precise method is to calculate the discharge using the head at the low end and the head at the high end and average the discharge derived from these two calculations. If this is done, the error is reduced to minor significance.



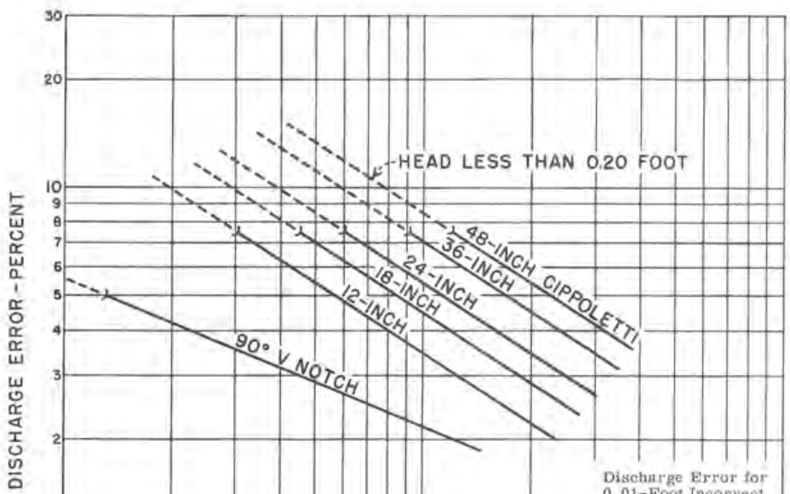
Error in Discharge for Head Measured at End of Cippoletti Weir Instead of Average Head.

If it is not known that the weir is inclined and the gage zero is referenced to either the high or low end, resulting error is considerably greater.

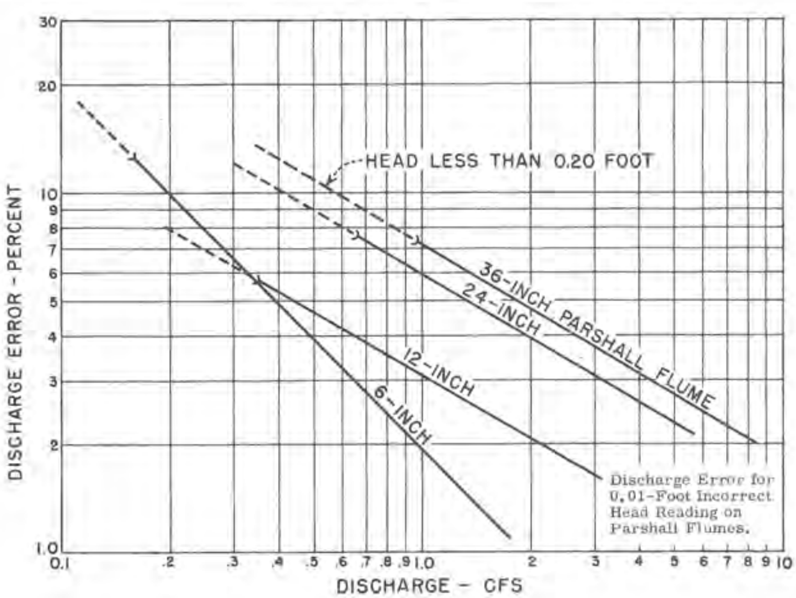
The figure, lower left, shows the magnitude of the error in discharge resulting from measurement of head at either end of 12-, 24-, 36-, and 48-inch Cippoletti weirs, having a transverse slope of 0.01, instead of using the average head over the weir. An inclination of about 6 degrees will cause an error in the order of 1 percent. An angle of this magnitude should be detectable by eye, and corrective measures taken.

Error in Discharge Resulting from Errors in Reading the Head

Perhaps the most common error in measuring irrigation water is to misread the head. This may result from incorrect location of the gage, or because the head gage is dirty, a stilling well is not used and there is considerable fluctuation of water surface, or carelessness on the part of the reader in not obtaining a good average reading at the time the gage is observed.



Discharge Error for 0.01-Foot Incorrect Head Reading on Weirs.

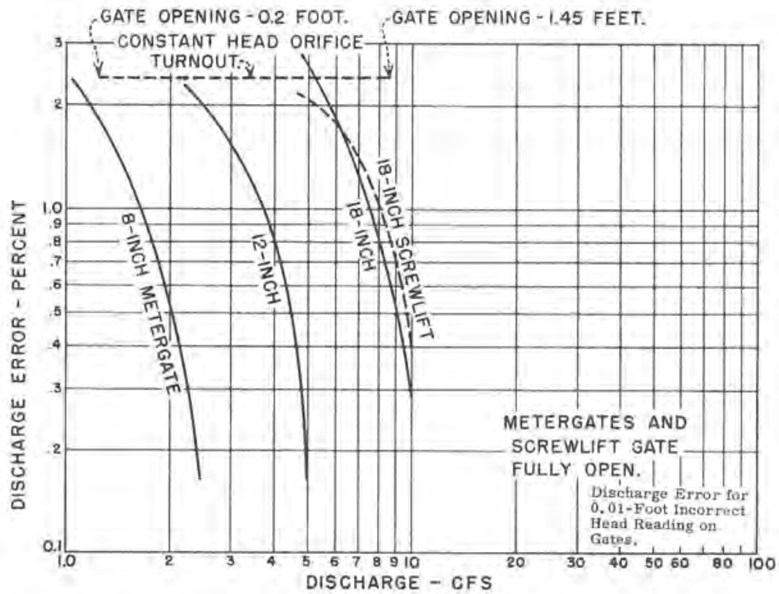


Discharge Error for 0.01-Foot Incorrect Head Reading on Parshall Flumes.

The figure, upper left, shows the error in discharge resulting from a 0.01-foot incorrect head reading on 12- to 48-inch Cippoletti and 90° V-notch weirs. This figure clearly illustrates that even with a small error of 0.01-foot, an error of approximately 7-1/2 percent in discharge results when the lower heads are being measured. For greater heads this error is less. Also, it can be noted that for the longer weirs this slight error in head reading results in quite large errors in discharge measurements.

As in the case of weirs, the head at the throat of a Parshall flume is quite easily misread in the field. The error in discharge resulting from misreading the gage only 0.01 foot is shown in the figure at lower left. Parshall flumes of throat widths of from 6- to 36-inches are shown in this figure. It can be noted that the error in general is approximately the same as for misreading the head an equal amount when weirs are considered.

The figure below shows the error in measurement resulting from an error of 0.01-foot in reading the head on 8-, 12-, and 18-inch screw-lift gates. The meter gate has a circular leaf and the screw-lift gate has a rectangular leaf. Included in the figure is the error caused by 0.01-foot incorrect head reading for the constant-head orifice turnout. It should be noted that the percentage error in discharge resulting from misreading the head on an orifice is in general less than the same misreading on a weir.



Error in Discharge Measurement Caused by Incorrect Zero Setting

The error for incorrect zero setting of the head gage is of the same magnitude as the error for misreading the head an equal amount. Improper positioning of the gage used to read the head is probably the most common error found. In the field it is difficult to reference the exact zero of the gage to the crest of a weir, a submerged orifice, or to a turnout gate. Extreme care should be exercised in setting the gages since incorrect setting cause errors in all flows, as shown in the figures on this and the preceding page.

Errors Resulting from Improper Gage Location

Proper location of the gage for obtaining head on measuring devices is important if errors are to be avoided. In most instances, flow relationships have been determined empirically with a particular type of gaging device placed in a specific location. Hence, there is included in the overall calibration a secondary effect of calibration of the gaging system employed to obtain the head. Because of changes in the flow pattern of the stream as it passes through the measuring section, minor deviations from the standard in gage design and location may appreciably affect the quality of the measurements.

In the case of a weir, there is a downward curve of the water surface as the flow passes through the notch. This curved surface, or drawdown, extends some distance upstream. The exact distance is dependent upon local conditions. The head of the weir must be measured beyond the effect of the drawdown. In the development of the basic weir formulas, the head was observed at distances upstream from the weir notch varying from about 4 to 9 times the maximum head over the weir. Therefore, many authorities have accepted a minimum distance of four times the maximum head to be measured. However, one authority says the distance should be at least 2.5 times the maximum head. Experiments by others have shown that there is some effect of drawdown to a distance of some six times the head on the weir. The influence at this greater distance is minor. Within the practical limits of the gages used at weir installations in irrigation systems, it appears that a distance upstream of four times the maximum head is quite adequate providing other criteria such as height of weir, width of weir pool, etc., are complied with.

Unpublished results of brief studies conducted in the Hydraulic Laboratory of the Bureau of Reclamation show that it is extremely difficult to detect differences of head on enameled staff gages located 2, 4, and 10 times the head on the weir. These same studies did show that positioning the enamel staff gage on the weir bulkhead, a practice sometimes followed in irrigation measurements, as shown in the photograph below, may result in errors. Certain positions on the bulkhead, with respect to the weir notch, gave a higher reading for certain flows than a gage correctly positioned. At other flows, the reading was less. As the gage on the bulkhead was moved away from the weir notch more consistent results were evident. It was found, for the flow conditions tested, that when the gage was placed on the weir bulkhead at a minimum distance of twice the maximum recommended head for the weir, the difference in the heads read on this gage and one correctly placed upstream was within the limits of visual observation.

When the velocity of approach is high and the irrigation channel has a high loss coefficient, there is a danger of placing the gage so far upstream from the weir crest that an error will prevail unless a correction is made for the loss of head due to channel friction between the point of measurement and the weir.

Errors in measurement can easily occur if the gages used in a Parshall flume are not placed in the manner and location developed in the standards. The ratings for this flume include a calibration of the gage positions. The gages are located in drawdown areas. Under these conditions, movement of the gage upstream or downstream from the standardized location will change the head reading and an error in discharge will result. For similar reasons, if a stilling well is used, the type and location of the entrance to the wells should be as specified. Substantial errors in field measurements have been traced to changes in location or design of the still well entrances.

Similar remarks apply to the location of the two gages used in the constant-head orifice turnout. The discharge tables developed from the calibration of this device are accurate only if the gages are placed in the location given in the standard drawings.

Discharge Errors Due to Neglecting Velocity of Approach to Weir

In practical application, the cross sectional area of the approach channel can usually be made sufficiently large in comparison with the weir notch to render the effect of velocity of approach negligible. If, however, the approach velocity is not maintained at or below 0.5 feet per second, it must be taken into account and a correction applied. In other words, if the normally used equation, charts, or tables are used, without correction for obtaining discharge from measured head an error will result.

In irrigation practice the velocity of approach to a weir is usually increased over that for which it was originally designed by: (1) a general restriction of the cross sectional area of the weir pool by deposits of vegetal growth, or (2) sediment or other accumulations in the bottom of the weir pool. Either will change the standards to which the weir installation should conform.

A general reduction of the cross sectional area of the weir pool will cause an increase in approach velocity which is directly related to the degree of restriction. The percentage error for a range of approach velocities and heads of weirs, except the V-notch type, is given in Table III on the next page. The error is such that the discharge is actually greater than that obtained from the discharge tables by the percentages given in Table III.

Authorities agree that the crest of the weir should be a distance not less than two times the depth of water over the crest above the bottom of the approach channel for accurate results. A greater height of weir crest is to be preferred when practicable. A weir installed in an irrigation channel in accordance with this standard may retain its accuracy for only a short period because of reduction of depth of the weir pool by sediment deposits, as shown in the photograph on page 6. The regularly used tables will no longer apply. The error may be reduced or possibly eliminated by use of Rehbock's formula for computing discharge from the head observations.

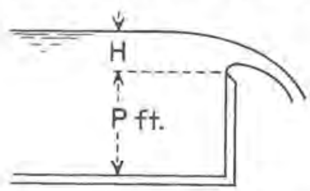
TABLE III

Discharge Error
Resulting from Failure to Correct
for Velocity of Approach

Velocity of Approach (ft./sec.)	Error in Percent Observed Head Over Weir - (Feet)				
	0.2	0.4	0.6	0.8	1.0
0.5	2.7	1.3	0.9	0.6	0.6
1.0	9.8	5.1	3.4	2.7	2.2
1.5	20.8	10.9	7.5	5.7	4.7
2.0	33.5	18.1	12.6	9.7	7.9
2.5	48.0	26.6	18.7	14.5	11.9
3.0	63.7	36.1	25.6	19.9	16.5

Table IV gives the percentage error in discharge that will occur if regular weir tables are used instead of correcting for the reduced height of weir by use of the Rehbock formula. The table is divided into two parts: The first part shows a constant head of 0.2-foot over a weir. The value of the ratio of H over P is varied and the error shown. The second part of the table is calculated for a constant head of 0.5 foot and is handled in a manner similar to the first part of the table.

TABLE IV
ERROR IN DISCHARGE FOR
CHANGES IN HEIGHT OF WEIR



WEIR HEIGHT P	$\frac{H}{P}$	COEFFICIENT K	% ERROR
Head = 0.2 foot			
0.5	0.4	3.49	5.6
1.0	0.2	3.41	2.7
2.0	0.1	3.37	1.5
3.0	0.07	3.35	0.9
∞	0	3.32	0
Head = 0.5 foot			
0.5	1.0	3.70	13.1
1.0	0.5	3.48	6.4
2.0	0.25	3.38	3.4
3.0	0.17	3.34	2.1
∞	0	3.27	0

This error is introduced in the field by improper maintenance and cleaning of the weir pool. As the pool fills the ratio of H over P increases and the error increases.

Numerous instances have been noted in the field where weirs have been placed in channels having relatively high gradients. It is very difficult to hold a properly proportioned weir pool under these conditions and obtain smooth flow through the weir notch. Obviously, the increased velocity of approach and turbulence will cause errors in measurement. Channel curvature and consequently poor velocity distribution over the weir crest will also cause excessive errors which are not easily evaluated. Laboratory experiments have shown that the extreme difference in discharge over a weir for a constant head, but with the upstream velocity distribution varied, amounted to 26 percent. A weir with very poor approach conditions is shown in the photograph above.

Discharge Error Due to Turbulence and Surges

Turbulence and surges occur in approach channels to weirs and other types of measuring devices. The cause is usually high velocity of approach but may be from gates or valves, sudden changes in section, or others. Such disturbances are usually evidenced by erratic results in measurements. The disturbances on the surface rarely follow a true sine wave pattern. Hence, the average reading of the head may cause appreciable error. Since the pattern is very complex, corrections are not readily applied to the calculations. Corrective measures to quiet the flow provide the best solution. This may not be an easy task.

Weir Blade Sloping Upstream or Downstream

In constructing a weir, it is necessary to have the plane of the upstream face of the weir vertical if accurate measurements are to be obtained. Experiments with sloping weirs show that the coefficient changes if the weir blade is tilted in an upstream or downstream direction; that is, when the face of the weir blade is not plumb. This change is slight, and the weir face may be out of plumb a few degrees before the accuracy of the measurement is seriously affected.

Roughness of Upstream Face of Weir and Bulkhead

For consistent and accurate flow measurements the upstream face of the bulkhead and weir blade must be smooth. Offsets, protruding bolt heads, and surface roughness must be avoided upon installation. Maintenance is necessary to retain a smooth surface. Sufficient work has not been done to provide an exact evaluation of the errors resulting from the many possibilities of roughness. It was found from one series of experiments that the percentage increase in discharge, due to changing the roughness of the upstream face of the weir bulkhead from that of a polished brass plate to that of a coarse file for a distance of 12 inches below the crest, is shown to range from about 2 percent for 0.50-foot head to about 1 percent for 1.35-foot head. Other experiments showed that when the upstream face of the weir was roughened, to the crest, with coarse sand (retained on No. 8 standard sieve and passing No. 4) that the increase in discharge ranged from 6.5 percent at a 0.2-foot head to 4.7 percent for a 0.5-foot head. The larger projections caused by the addition of nuts and pieces of metal on the bulkhead below the crest in these same experiments caused about the same increase in discharge.

Rounding of Sharp Edge at Crest of Weir

In irrigation practice many of the older weirs were constructed of wood. In this type of construction the original sharp edge of the crest soon becomes rounded. Rust and corrosion also produce a rounding effect on metal weir blades. The effect of this rounding is to cause an increase in the flow rate for a given head when compared to a sharp crested weir. Considerable experimentation has been done to evaluate the effect of the rounding of the crest. The results show that the percentage increase in discharge due to the rounding, decreases as the head increases. For a head of 0.5-foot, an increase of some 2, 3, 5-1/2, 11, and 13-1/2 percent may be expected for roundings having radii of 1/24, 1/8, 1/4, 1/2 and 3/4 inch, respectively. There is a deficiency of data for the higher heads with the longer radius roundings. However, with radii smaller than those given above, the increases become consistently smaller as the head increases. As an example, the increase in discharge of 2 percent, given above for the 1/24-inch rounding at 0.5-foot

head, becomes 0.7 percent at 1.0-foot head and about 0.5 percent at 1.35-foot head. An extreme example of rounding of a weir crest is that shown in the photograph on the preceding page.

Submergence of Weirs

For the measurement of irrigation water it is not the usual practice to install weirs where submergence is anticipated. However, changes in the regimen of the channel downstream may cause a weir to operate under submerged conditions. Submerged flow, at its best, is relatively unstable. Therefore, the results of the studies of submerged weirs are not in good agreement and it may be concluded that measurements made by a submerged weir should be considered as approximate only. One solution is to remove the cause of submergence from the downstream channel if this is practicable.

Aeration of the Downstream Nappe of a Weir

One of the general conditions for accurate and consistent measurements by contracted weirs is that air circulates freely on all sides of the flow issuing from the weir notch. Such conditions ordinarily are not difficult to obtain. The weir bulkhead in irrigation structures is constructed of concrete in many instances. The use of metal weir blades which do not project a sufficient distance from the concrete, or an improper bevel of the concrete downstream from the blades can easily restrict the desired air circulation. The effect of this restriction of air is to increase the flow rate for a given head. The increase in discharge will depend on the degree of restriction of air and can be appreciable.

The problem is more pronounced when suppressed weirs are used. For standard suppressed rectangular weirs used in irrigation practice, the sidewalls are generally carried straight through the structure. Thus, auxiliary means must be provided to supply air to the underside of the nappe. Unless adequate air is provided to this area to replace that carried away by the jet, a partial vacuum will be formed. The result is a lowering of the nappe and an increase in discharge over that obtained with adequate aeration. A condition of instability may also exist in which some erratic measurements will be obtained. One investigator found that the discharge would be increased about 3-1/2 percent at 0.5-foot head and about 2 percent at 1.0-foot head when the pressure under the nappe was reduced only 0.8-inch of water below atmospheric. When the pressure was further reduced to 1.2 inches of water, below atmospheric, the increase in discharge was about 5 percent and 2-3/4 percent for heads of 0.5 and 1.0-foot, respectively. The size of vents adequate to relieve this negative pressure will depend on conditions at the weir. Two investigators have developed solutions for calculating the size of vents. The important consideration is to design the vents of adequate proportions to relieve the low pressure insofar as it is possible.

Other Factors Affecting the Accuracy of Discharge Measurements Over Weirs

There are factors, other than those covered separately above, which may cause errors in discharge measurements made with weirs. Many of them apply equally as well to other types of structures and devices.

Obstructions in the measuring section cause errors proportionate to the magnitude of such an obstruction. In irrigation systems floating detritus, weeds, moss, etc., may obstruct the water passage, as shown in the photograph at left. Frequent and close inspection accompanied by remedial measures will relieve this condition.

Changes in viscosity and surface tension of the fluid are known to alter the flow coefficient. However, the effect of these two factors are considered negligible in irrigation systems where the flow media is water, and wide variations of temperatures are not encountered and, further, provided the restrictions on high and low heads over the weir are complied with.

At very low heads, flow over a weir may become quite unstable and errors and inconsistencies in the measurements will result. Because of viscous drag and the tendency of the nappe to adhere to the weir crest there is general agreement among experimenters that heads of less than 0.2-foot will not produce reliable results when the usual discharge tables or formulas are used.

The results of many experiments on weirs show that the formulas developed for rectangular weirs do not hold when the head exceeds about one-third of the length. There are indications that the discharge formula for the Cippoletti weir, in lengths over 1-foot, is slightly in error at heads less than one-third the length. Possibly the rule should be that the head should not exceed one-fourth of the length if errors are to be reduced to a minimum.

As previously stated, the flow formulas for weirs have been developed empirically and are not necessarily susceptible to extrapolation. Most of the data have been derived for heads up to 2.0 feet. Although some data are available for higher heads, authorities generally agree that a 2.0-foot head should not be exceeded for any length weir if good quality results are desired.

It has been previously pointed out that the percentage of error in discharge resulting from a given error in measuring the head will decrease as the head increases. Therefore, the minimum error and, hence, the greater accuracy can be expected if the discharge occurs under the maximum head commensurate with the above limitations.

Careful visual inspections made at regular intervals will remove many of the sources of error mentioned above. These inspections should also disclose other sources of errors such as leaks around the measuring structure, through weir bulkheads, or from drains in the structure.

CONCLUSIONS

The charts, tables, and discussions presented in this article are not intended to point out all the possible errors in all the devices and structures used in measuring irrigation water. However, from the examples cited, the following conclusions may be drawn.

To obtain accurate measurements of irrigation water it is necessary to make a careful study for the selection of a proper device to fit the conditions pertaining at the site. Even with careful planning and selection of an excellent primary measuring device, it is probable that errors may be introduced into the measurements unless due care is exercised in fabrication, installation, operation and proper maintenance of the devices or structures. The magnitude of these errors can be appreciable and the value of a well planned measuring program may be reduced considerably by failure to anticipate and remove the cause of the errors.

The possible errors cited are both negative and positive and may tend to cancel each other. However, more careful scrutiny shows, especially in the case of weirs, the probability is that there is a predominance of negative errors. This means then that usually more water is being delivered than is apparent from the measurements.

Notes:

Equation "A"

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

Equation "B"

$$Q = 4WH_a^{1.522W^{0.026}}$$

* * * * *

USE OF STAINLESS STEEL WIRE ROPES FOR HOISTS

The use of stainless steel hoisting rope for radial gates has been gaining favor among operating supervisors during the last few years because it has the desirable effect of increasing rope life and reducing the hazard of rope failure due to corrosion. This practice has been, and will continue to be encouraged where it appears to be economically advantageous.

A word of caution is appropriate, however, as pointed up by a recent failure of stainless steel hoisting ropes after about six months of service at a loading of only about one-eighth of breaking strength. The failure occured on an automatic gate and was due to hunting over a range of 2 or 3 inches.

The major break shown above was a few inches above the point of attachment to the gate, where the rope was straight and not subject to bending; but breakage of single wires had occurred all through the rope structure as shown on the more detail photographs on the following page, and particularly where the rope was flexing as it ran on and off the drum.

Stainless steel is very susceptible to work hardening. Military Specifications No. MIL-C-5424 allow a 50-percent reduction in tensile strength after 50,000 bending reversals of 1/4-inch 6 by 9 stainless steel rope. Fewer reversals would be required to produce a similar weakening of larger ropes. Individual wires of a rope are subject to torsional, as well as tensile, stresses when the rope is under straight tension; and each wire twists and untwists if the rope pull is alternately increased and decreased. This explains the failure of the ropes at a point of straight tension.

Stainless steel wire rope should not be used on gates which are likely to hunt and the need for lubrication of stainless ropes should not be overlooked. Keystone wire cable grease is recommended.

This grease is free of tars and gummy substances that will flake off on drying and is of a consistency that will penetrate to the center of the cable.

We suggest that all stainless steel ropes now in service be examined minutely, at the convenience of operating personnel, for possible breakage of individual wires as shown in the photographs above. If any such breakage is discovered, it should be reported along with the conditions of operation and service. An alarm is not being sounded, as the one case of failure was due to very unusual operating conditions. However, due to the possibility of extensive damage to facilities in case of rope breakage, a careful investigation is warranted; and operating personnel who may be using or considering the use of stainless steel rope should be informed of its inherent work-hardening characteristics, and its limitations under continuous flexing.

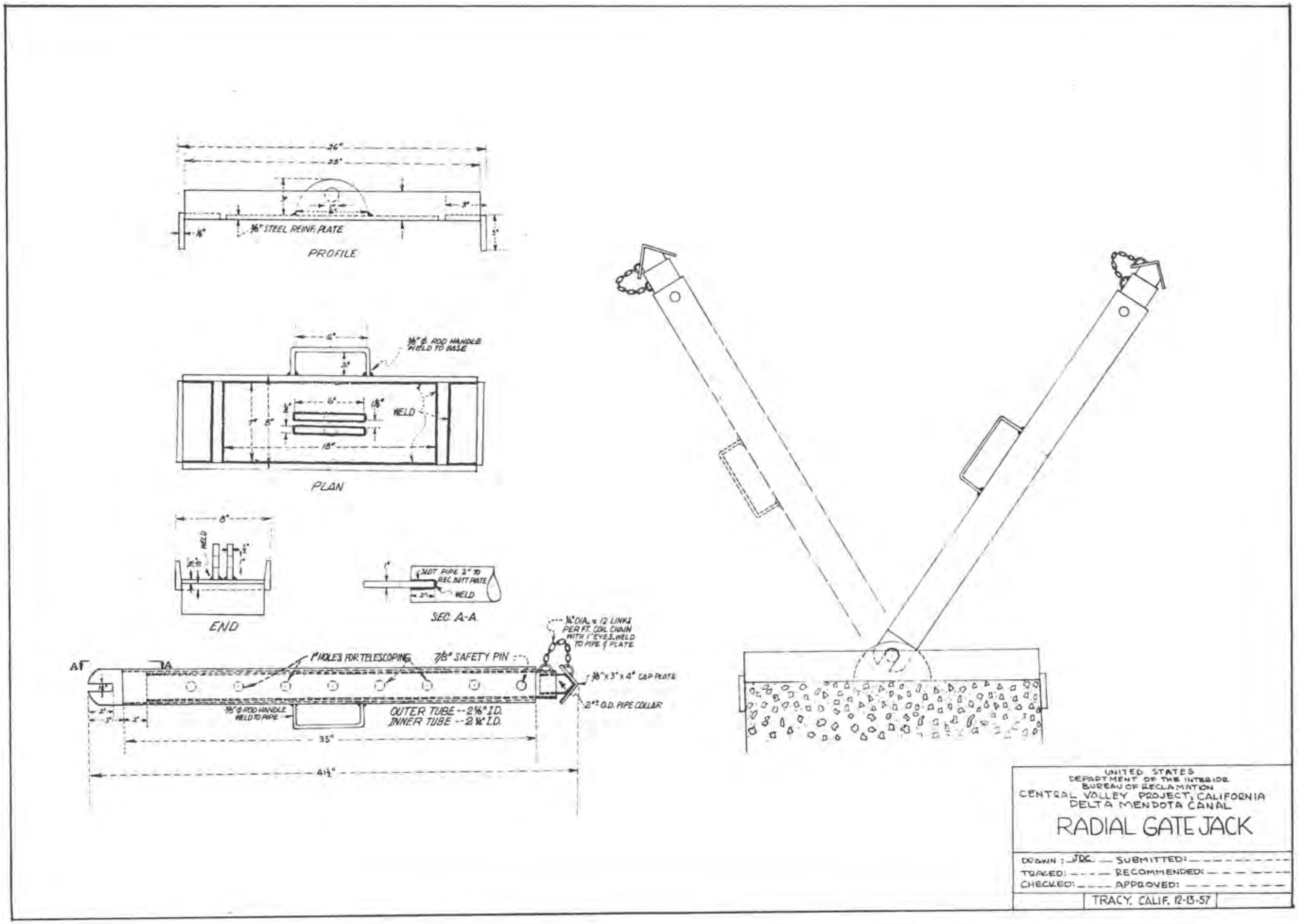
* * * * *

SPECIAL JACK SUPPORTS RADIAL GATES
(Suggestion No. R2-57-94)

In changing the hoist cables of the radial check gates on the Delta-Mendota Canal of the Central Valley Project, it is necessary to secure the gate in an open position while the old cables are removed, and the new ones installed. Since the cables must be changed when there is water in the canal, this can be a slow and also hazardous undertaking using the previous method of putting a sling and chains around the operating deck to support the gate. A special jack built by Robert H. Vouch, Tracy Operations Field Branch, is light, and makes it possible to do the work required in a much easier, safer, and less costly manner.

In addition to the photographs of the jack above, a sketch of the parts is shown on the following page. Two jacks are used, one on each side of the gate, during the cable replacement.

* * * * *



26"
25"
3"
6"
3"
⅛"
⅜" STEEL REINF. PLATE
5"
PROFILE
6"
⅜" ϕ ROD HANDLE WELD TO BASE
2"
6"
1⅛"
7" 8"
WELD
18"
PLAN
8"
WELD
END
SLOT PIPE 2" TO REC. BUTT PLATE
2"
WELD
SEC. A-A
A
A
1" HOLES FOR TELESCOPING
7/8" SAFETY PIN
¼" DIA. x 12 LINKS PER FT. COIL CHAIN WITH 1" EYES, WELD TO PIPE & PLATE
⅜" x 3" x 4" CAP PLATE
2" O.D. PIPE COLLAR
⅜" ϕ ROD HANDLE WELD TO PIPE
OUTER TUBE -- 2⅜" I.D.
INNER TUBE -- 2¼" I.D.
2"
3"
2"
35"
41½"
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT, CALIFORNIA
DELTA MENDOTA CANAL
RADIAL GATE JACK
DRAWN: JDC
SUBMITTED:
TRACED:
RECOMMENDED:
CHECKED:
APPROVED:
TRACY, CALIF. 12-13-57

PRECAST CONCRETE BLOCKS FOR MINOR STRUCTURES

One of the major problems on operating projects in many areas is the inability to perform the concrete work for minor water control structures during the frost free period of the year. The use of precast concrete blocks to build minor structures, instead of placing concrete on the job, affords many conveniences, as well as a saving in construction costs, especially when the jobs are located in a remote area. The Uncompahgre Project in western Colorado has utilized precast concrete blocks in the replacement of minor structures since 1954. Typical of a drop structure constructed with the blocks is that shown below.

The first structure using precast concrete blocks was constructed in 1954; since that time an additional 25 structures have been completed. Jesse R. Thompson, now retired, former Manager of the Project for the Uncompahgre Water Users' Association, Montrose, Colorado, designed a set of forms to precast 2' x 2' x 4" and 1' x 2' x 4" concrete blocks to be used in the construction of drops, chutes, headwalls, and other minor water control structures. A drop of 6 feet, in a 4-foot wide channel with the structure 10 feet long can be placed with the precast blocks for approximately 60 to 65 percent of the cost of a similar drop on which the concrete is placed on the job during subfreezing temperatures.

Other advantages in the use of the blocks are:

1. Blocks may be cast and properly cured during warm weather, or easily protected from frost during cold weather.

2. There is no waste of aggregate or cement.

3. Use of the blocks eliminates transportation of a mixer for mixing concrete in cold weather; and protecting concrete from freezing.

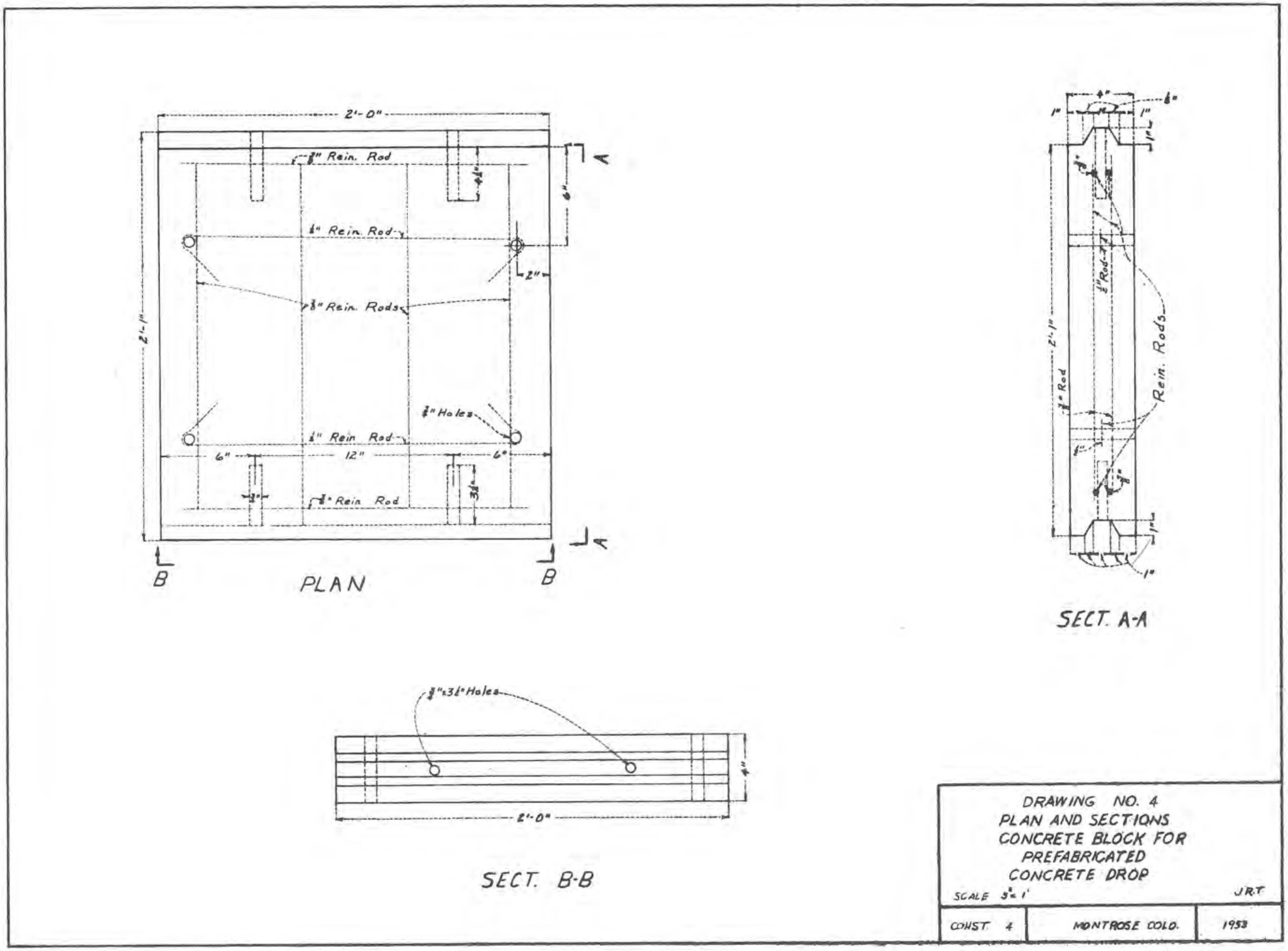
4. A drop of the dimensions given above can be placed in about 1/3 the time required to place concrete on the job.

5. No damage results if inclement weather occurs during construction, and it becomes necessary to suspend work.

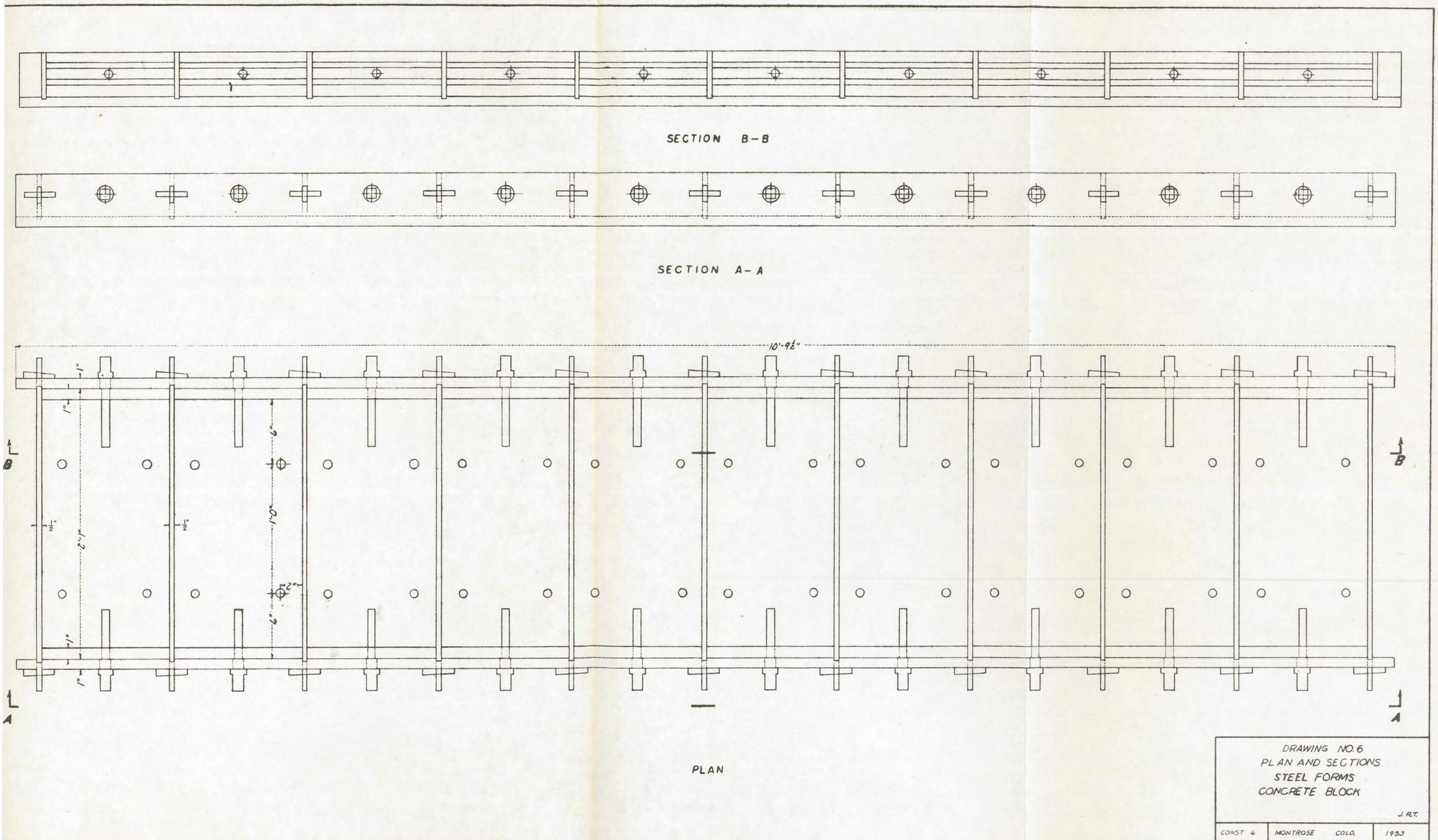
Construction

Only two men are required to fabricate and stockpile the prefabricated blocks. The forms are bolted to permanent trestles at about average waist height, as shown in the photograph below, for convenience in assembling the forms, troweling the concrete, and moving the finished blocks from the forms to the stockpile.

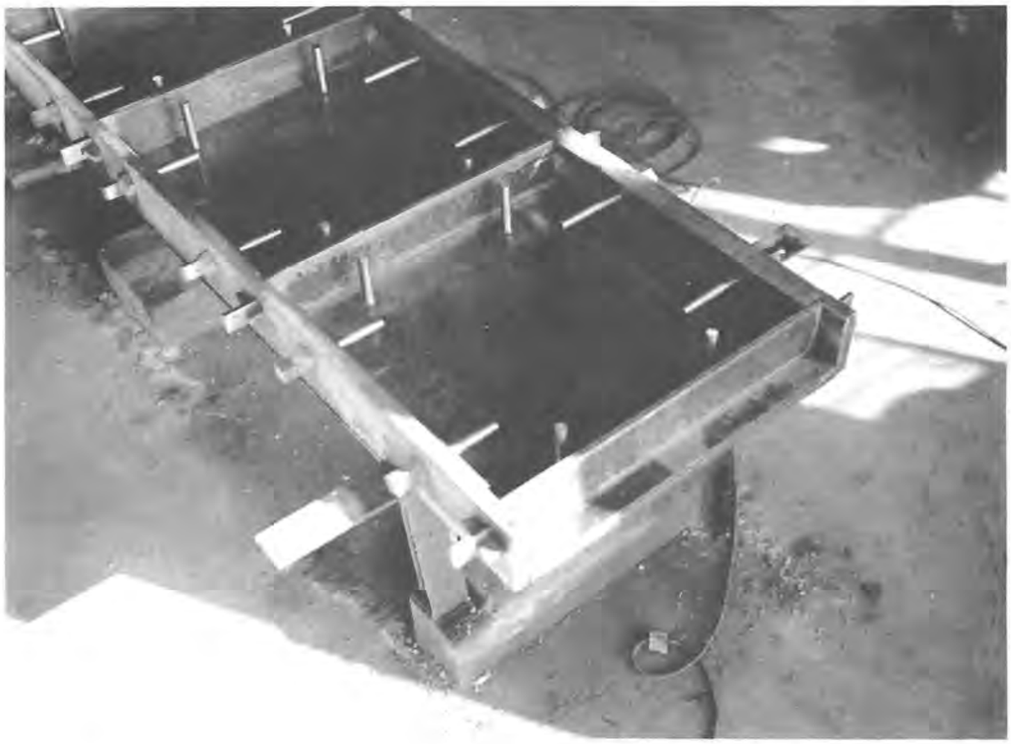
The blocks are made with dove-tailed joints, and are also joined together horizontally by the use of bolts and strap iron. Vertically they are joined together by placing 8-inch lengths of 5/8-inch reinforcing steel in the holes provided in their manufacture. Design details of the blocks and block forms are shown in the drawings on the following pages.



PLAN
SECT. A-A
SECT. B-B
2'-0"
2'-1"
Rein. Rod
Rein. Rods
Holes
12"
6"
2"
4"
1"
Reln. Rods
DRAWING NO. 4
PLAN AND SECTIONS
CONCRETE BLOCK FOR
PREFABRICATED
CONCRETE DROP
SCALE
J.R.T.
CONST. 4
MONTROSE COLO.
1953


SECTION B-B
SECTION A-A
10'-9½"
1"
2'-1"
1'-0"
6"
½"
2"
B
A
PLAN
DRAWING NO. 6
PLAN AND SECTIONS
STEEL FORMS
CONCRETE BLOCK
J.R.T.
CONST 6
MONTROSE COLO.
1933

A close-up view of one of the forms is shown below. A bar bending machine, set up in the building, is used to bend the reinforcing bars, and to make U-bolts as needed.



The type of structure that can be constructed with the blocks is quite impressive. There was no leakage of water through the joints between the blocks of the structures examined, and the walls appeared to be rigid and sturdy. There is, of course, a limit to the height of wingwalls and headwalls that can be built without the use of struts to support the pressure from earth or water. The project utilizes an air entraining agent in the concrete used in the blocks and the aggregate is carefully measured. Blocks are cured with curing compound. It is understood that two sets of steel forms were built for the project by a steel fabrication company at a cost of about $1,700. However, it seems probable that less expensive wood forms might be utilized if a less extensive program were being contemplated.

In the event that there should be questions relative to the design of the blocks or the methods of construction, contact H. F. Bahmeier, Project Manager, U. S. Bureau of Reclamation, P. O. Box 780, Grand Junction, Colorado.

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FARM GATES REPLACE CATTLEGUARD
(Suggestion No. R2-57-54)

Where a bridge is used for transferring cattle across the Friant-Kern Canal, Central Valley Project, California, use is being made of 16-foot metal farm gates instead of constructing or replacing cattleguards. The gates serve a dual purpose. The large double gates shown in the first photograph below can be opened and swung into position shown in the lower photograph to close off the canal roadway leaving an open runway for the cattle to cross the canal bridge.

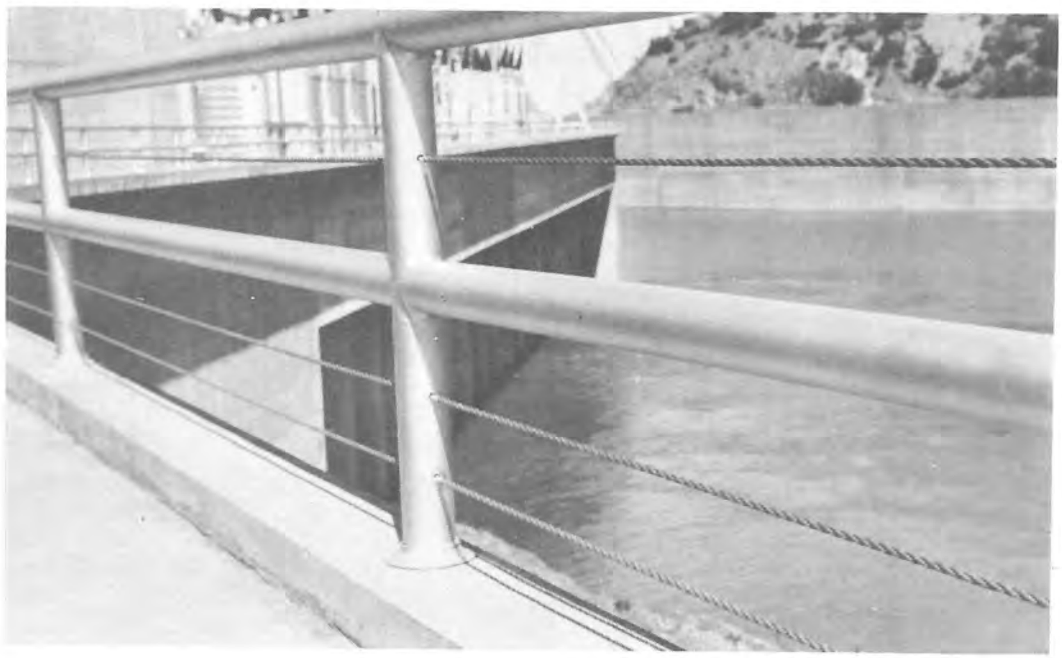
Other similar installations are to be made in the Central Valley Project to replace numerous cattleguards. It has been estimated that in replacing eight old cattleguards on the Orange Cove Unit of the Project, use of Canal Superintendent E. I. Curran's suggestion has saved upwards to $500 per installation over the cost of the conventional cattleguards.

There are a great many places where the movement of cattle across a canal is done only occasionally, and this suggestion, rather than the installation of cattleguards, will serve to solve the problem very nicely.

* * * * *

CABLES SUPPLEMENT GUARDRAIL PROTECTION

Galvanized cables have been added to the guardrails in the vicinity of the Shasta Power Plant, Central Valley Project, California, as shown below, to provide additional protection to visitors, particularly small children. The additional protection afforded by the cables is quickly and easily obtained where guardrail posts of the type shown are in existence.



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