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LABORATORY CALIBRATION TESTING OF A NONSTANDARD PARSHALL FLUME

PURPOSE

A laboratory calibration was performed to develop a discharge relationship for a nonstandard, 1-foot Parshall flume. Irrigation districts throughout Montana are having difficulties verifying discharge measurements using flumes similar to the one calibrated. Because of the large number of similar flumes in use, a single laboratory calibration was preferred over individual field calibration tests.

INTRODUCTION

A laboratory calibration was requested by the Montana Projects Office (MPO) to verify the accuracy of a nonstandard Parshall flume manufactured by Rosco Steel of Billings, Montana. There were over 2,000 of these flumes in use at the time of this study. The purpose of the laboratory calibration was to determine if the discharge relationship for a standard Parshall flume is altered when it is installed without upstream or downstream transition sections. The standard practice is install the flume with 45° or curved wingwall transitions located at both the entrance and exit sections, as specified in Reclamation's *Water Measurement Manual* (Reclamation, 1967).

Irrigation districts using these flumes have had difficulties verifying the accuracy of discharge measurements from the "Montana" flume. As a result, a 1-foot Parshall flume was obtained from Rosco Steel and calibrated in Reclamation's Hydraulic Laboratory.
This report presents the results of the free flow calibration for this particular flume installation.

The following conclusions are based on calibration results for one representative Parshall flume installed according to a typical field application. Twenty-one discharge measurements were taken for flowrates ranging from 0.35 to 17.19 ft^3/s.

SUMMARY AND CONCLUSIONS

- The overall performance of the "Montana" Parshall flume, tested in Reclamation's Hydraulic Laboratory, was within the expected standard error of ± 3 to 5 percent for a Parshall flume. The flume performed well despite noticeable steel warpage in the flume walls and bottom.

- Errors in excess of 5 percent that are experienced at "Montana" flume field sites are likely caused by improper installation or maintenance practices. In general, site surveys reveal that the many Parshall flume installations have been improperly constructed or maintained. However, when these problems were corrected they performed within the expected accuracy of ± 3-5 percent of the true discharge.

- Ninety degree headwalls at the upstream and downstream ends of the 1-foot flume do not create significant waves at the staff gage until discharges are greater than 6.0 ft^3/s. At this flow, the H_a reading varied by ± 0.01 foot or ± 0.09 ft^3/s. At flows greater than 12 ft^3/s, the water surface at H_a varied by ± 0.02 foot or ± 0.20 ft^3/s.

- If care is taken, an accurate value for H_a can be measured using the staff gage. However, a stilling well and level recorder is the preferred method for level measurement, because it provides an average H_a value and can be equipped to create a permanent record of daily discharges. The point gage measurements at the centerline of the flume did not give accurate head measurements; the average error was nearly 5 percent.

- When sizing a Parshall flume for a specific installation, it is recommended that the flume operate in the upper 85 percent of the recommended flow range. This criteria will help minimize the discharge measurements taken in the flow ranges where accurate measurements are difficult. In other words, do not overdesign the flume with an additional discharge capacity because it can result in a flume which frequently operates in the lower 15 percent of published flow range.

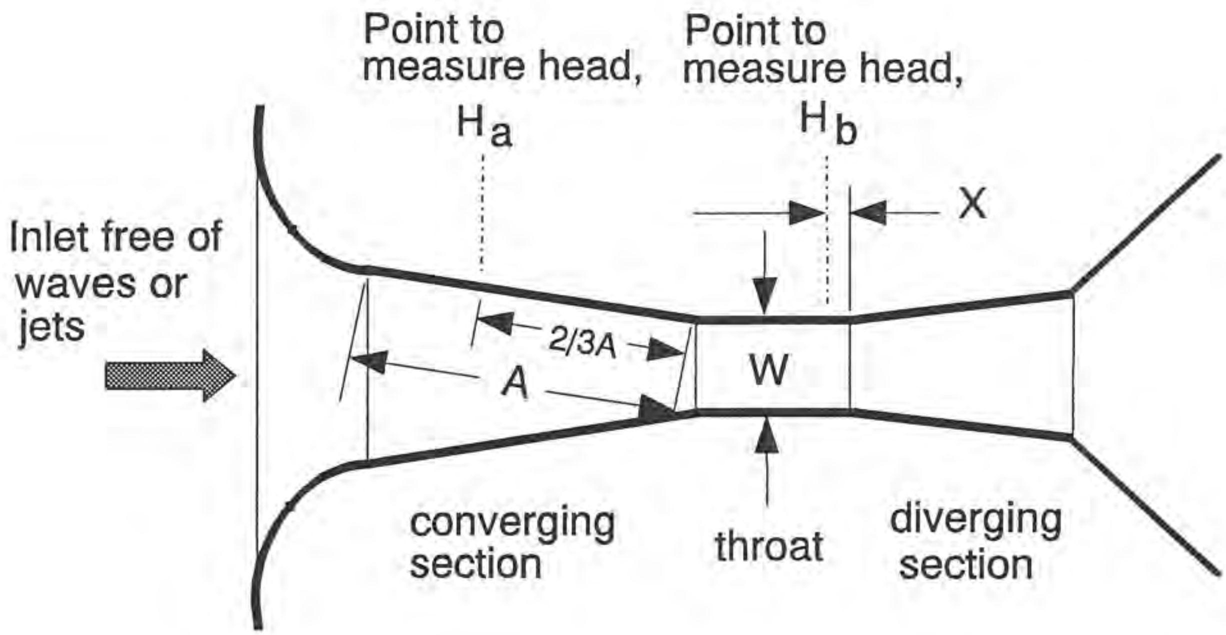
- Flume construction should include additional reinforcement so that deformation does not occur during transportation or while backfilling during installation. Tolerances for flume dimensions should also be monitored during fabrication and installation.

- The H_a piezometer tap is not properly located when compared to a standard Parshall flume. The tap location for H_a should be located 0.2 foot above the crest. This position prevents discharge measurements during very low flows, which are not accurately calculated using the standard discharge equation. Likewise, it also prevents sediment from accumulating in the stilling well system.

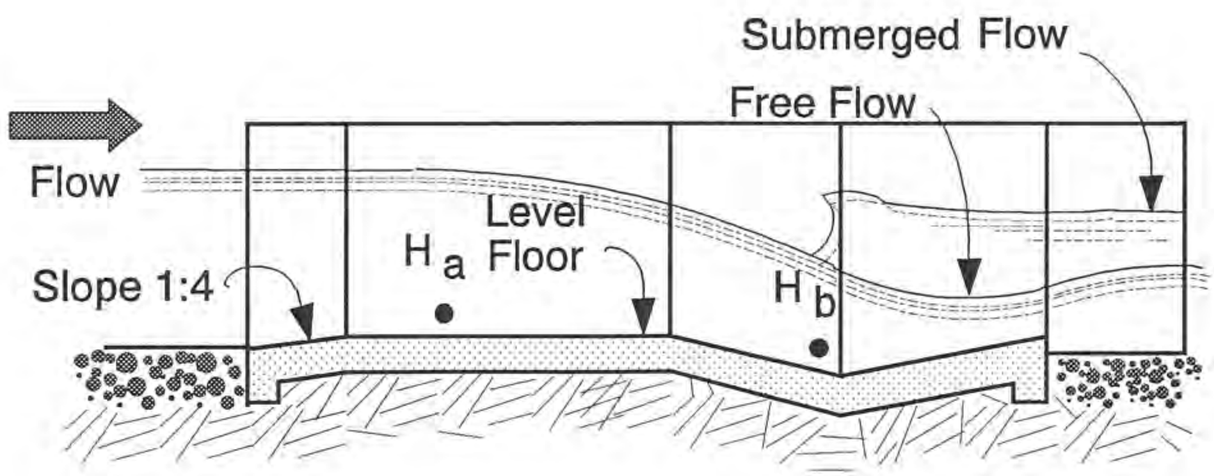
BACKGROUND

The Parshall flume is one of the most common devices used to measure the flow rates in an open channel, usually a canal or irrigation ditch. As a result, the Parshall flume has been extensively tested by researchers in an effort to define and improve the empirical discharge relationships for free and submerged flow conditions.

Free flow occurs when water can pass through the flume without restriction caused by downstream flow conditions, i.e. backwater caused by a check structure (see fig. 1). Conversely, submerged flow occurs when the downstream flow depths are high enough to restrict flow through the flume. For free flow conditions, discharge through the flume can be calculated based on a single head or depth measurement at a specified location, which is commonly designated as H_a. Whereas, with submerged flow, a second head measurement at location H_b is necessary to establish the degree or percentage of submergence. Once the submergence is known, a separate discharge relationship can be employed to calculate the flowrate.



Plan View



Profile View

Figure 1. Plan and Profile views of a standard Parshall Flume.

Recently, research was conducted to develop improved methods for calculating discharge for submerged flow. Additional information on this subject can be obtained from a professional paper entitled "Submerged Flow in Parshall Flumes" (Peck, 1988). Therefore, it is recommended that to achieve an accuracy within ±3 to 5 percent of the true discharge, the flume should operate under free flow conditions.

Figure 2. View of "Montana" Parshall flume installation (looking downstream).

To accurately measure flow with a Parshall flume, several conditions must be satisfied, these include:

- The standard flume dimensions must be maintained during construction and over the life of the flume. Structural rigidity must be adequate so that it does not deform during construction or during its service life.

- The crest (the floor in the converging section, see fig. 1) must be level both longitudinally and laterally. Studies of a 3-inch Parshall flume showed that longitudinal slopes of ±10 percent can cause errors of 32 percent (Abt, et al. 1989,1990). Similar results can be expected for larger flumes as well.

- The flume should be located in a channel reach with a long, straight approach (~10 channel widths) without any obstructions. Flow entering the flume should be tranquil and have a uniform velocity distribution so an accurate head measurement can be gaged. Velocity distributions can be determined using common stream gaging techniques.

- The secondary elements of the flow measurement system, such as the stilling well, staff gage, or level sensor, must be properly located and calibrated with respect to the crest elevation. They must also be maintained to ensure the calibration constants are not changing due to sediment, algae, or settlement.

- The flume must be installed on a solid foundation so it does not settle or allow seepage around the structure. The flume should have clean, smooth flow surfaces.

- It must be known if the flume is under free or submerged flow conditions at the time discharge is measured. This can be accomplished by installing a staff gage to measure H_b.

If any of the above conditions are not satisfied, significant error in flow measurement will result. In most cases, an underestimate of discharge is measured.

TEST FACILITY AND EXPERIMENTAL PROGRAM

The "Montana" Parshall flume was installed in an existing canal section which was used for researching submerged flow through a standard, 1-foot Parshall flume (Peck, 1988). The test facility is located in Reclamation's Hydraulic Laboratory, in Denver, Colorado. The canal is 36-feet long, has a 2-foot bottom width and 1.5H:1V side slopes (fig. 1). During a survey of the "Montana" flume, it was determined that all dimensions were accurate except the diverging section length was 2.96 feet, which is slightly less than the accepted length of 3.0 feet as published in Reclamation's *Water Measurement Manual*. Also the location of H_a is not 0.2 feet above the crest, as recommended. In addition, the converging section has a convexed crest of approximately 3/8 inch at the cross section through H_a. The sidewalls were bowed outward up to 1/2 inch for both the converging and diverging sections (fig. 1), whereas the walls in the throat section were bowed inward up to 3/8 inch.

Due to structural irregularities, the flume could only be leveled to within $\pm 3/16$ inch both laterally and longitudinally. The flume was set so the floor of the diverging section was at the same elevation of the downstream canal invert. As a result, the crest section was approximately 3 inches higher than the upstream canal invert. A transition from the canal invert to the flume was constructed of grouted cobbles and gravel at a 1:3 slope. Headwalls (located at 90° with respect to the flow direction) were used at the entrance and exit to the flume; they extended outward to the intersection with the canal side slopes.

Head measurements of H_a were taken with a staff gage, a stilling well with a hook gage, and a point gage (fig. 3). The staff gage was fastened to the side of the flume with its zero mark referenced to the crest elevation. The staff gage was read to the smallest division of 0.01 feet. The staff gage and stilling well were positioned at the H_a port, and the point gage was located at the intersection of the flume centerline and the cross section through H_a. All hook and point gages were observed to the nearest 0.001 of a foot and were referenced, using an automatic level and surveying rod, to the average crest elevation. A second stilling well and hook gage were installed at H_b to confirm free flow conditions. However, no attempt was made to create backwater on the flume.

Figure 3. Head measurement equipment at H_a.

The maximum free flow capacity for a 1-foot Parshall flume is published (Reclamation, 1967) as 16 ft^3/s, which is well within the capacity of the laboratory water supply system. The water was supplied by centrifugal pumps from a storage reservoir located below the laboratory floor. The water was delivered to the canal via two 12-inch-diameter pipes. The water passes through a gravel-filled baffle to provide uniform and tranquil flow entering the canal model. At the end of the canal, water is returned to the reservoir for reuse. The calibration discharges were measured using permanent laboratory venturi meters. The venturi's are periodically calibrated to an accuracy of ± 0.5 percent, using volumetric calibration techniques. Differential pressures across the venturi were measured to the nearest 0.001 foot using a differential mercury manometer.

As with every experiment, care must be taken to eliminate any sources of error in all data collected. Unlike field calibrations, laboratory conditions can be controlled to minimize uncertainty in the data acquisition. Sources of error for this calibration include: venturi measurement standard calibration (± 0.5 percent), head measurements at H_a (0.01 ft for staff gage), leakage from the test facility (~ 10 gal/min or 0.02 ft^3/s), and variations in flume cross section. However, all these conditions may also be present in a field installation.

CALIBRATION RESULTS

Discharge and head measurements were taken over a range of discharges from 0.35 to 17 ft^3/s. The calibration was performed to determine if head measurements taken at H_a and converted to flow rates using the standard Parshall flume calibration equation (equation 1) correspond to the discharge measured with the venturi meters.

$$Q=4*W*H_a^{1.522W^{0.026}}$$

Equation 1. Standard free flow equation for flumes with throat widths (W) from 1 to 8 feet (Reclamation, 1967).

The results for the free flow calibration are presented in table 1. The calibration results indicated that discharges measured using all three H_a values yielded flow measurements within the expected accuracy of $\pm$ 5 percent for the entire range of flows. These data were also compared to free flow data from the standard 1-foot Parshall flume used in a 1988 Reclamation study of submerged flow characteristics. The Parshall flume installation was similar except that 45° wing wall transitions were used both upstream and downstream of the flume. Likewise, a 1:3 rather than a 1:4 transition was used at the upstream invert.

A comparison of percent error in free flow discharge, using stilling well head measurements, between the "Montana" and Reclamation-1988 Parshall flumes indicates that the "Montana" flume consistently underestimates the discharge relative to the Reclamation (Peck, 1988) data (fig. 4). Likewise, a comparison of Parshall's free flow data (Parshall, 1928, 1936) and "Montana" flume data showed similar trends (fig. 5).

The majority of the "Montana" flume discharge measurements had positive errors which indicate a systematic error which causes an underestimation in the flow measurement. This error is most likely due to bowed walls of the converging section and includes the small amount of leakage in the model. The bowed walls result in a larger cross-sectional area; consequently, the flume will pass a discharge greater than the value calculated using H_a. However, as discharge increases this systematic error is a smaller percentage of the overall flow. The staff gage and stilling well H_a data support this concept. Whereas, the point gage measured the depth in the center of the flume where the flow depths are slightly greater due to the cross wave generated from the blunt transition.

Table 1. - Parshall flume calibration results for three different measurements of H_a.

$Q_{venturi}$ (ft^3/s)	$Q_{staff\ gage}$ (ft^3/s)	$Q_{stilling\ well}$ (ft^3/s)	$Q_{point\ gage}$ (ft^3/s)	Err_{staff}* (%)	Err_{well} (%)	Err_{point} (%)
0.35	0.35	0.37	0.41	1.34	-4.72	-18.03
1.01	0.99	1.04	1.09	1.53	-3.00	-7.99
1.50	1.48	1.55	1.56	1.52	-3.13	-3.72
1.99	1.93	1.97	2.02	2.76	0.84	-1.57
2.48	2.43	2.45	2.48	2.23	1.20	-0.05
2.98	2.85	2.89	2.94	4.46	3.00	1.35
4.00	3.82	3.89	3.94	4.57	2.77	1.41
4.96	4.75	4.79	4.84	4.11	3.46	2.41
5.98	5.82	5.85	5.90	2.67	2.32	1.40
7.02	6.82	6.81	6.87	2.86	3.07	2.13
8.02	7.79	7.79	7.88	2.81	2.90	1.76
9.12	8.89	8.87	8.97	2.54	2.72	1.66
8.99	8.73	8.73	8.85	2.93	2.93	1.60
9.88	9.70	9.62	9.74	1.75	2.59	1.33
11.02	10.80	10.78	10.92	2.06	2.21	0.89
12.09	11.93	11.88	12.06	1.34	1.71	0.24
13.12	13.00	12.92	13.10	0.87	1.56	0.17
14.11	14.02	13.93	14.15	0.60	1.27	-0.33
14.98	14.97	14.83	15.04	0.04	1.00	-0.41
16.08	15.94	15.95	16.13	0.91	0.85	-0.31
17.19	17.23	17.00	17.23	-0.22	1.12	-0.22
Standard deviation of percent error (σ)				1.29	2.17	4.47
Average value of percent error ($\bar{E}$)				2.08	1.27	-0.77

* $\%err_i = \left(\frac{Q_{VENT_i} - Q_i}{Q_{VENT_i}}\right) * 100$

The staff gage and stilling well measurements of H_a had an average error of +2.1 percent and +1.3 percent, and standard deviations of 1.3 and 2.2 percent, respectively (table 1). The smaller standard deviation for the staff gage measurement is surprising considering the fluctuation in the water surface, especially at larger flows. Perhaps this can be attributed to carefully averaging each staff gage reading. The H_a values measured using the point gage had the largest standard deviation, which was +4.5 percent. The results indicated overestimates (1.5 to 18 percent) in discharge for values less than 2 ft³/s. This was caused by a bulge in the flume floor which at low flows results in an exaggerated H_a measurement and a reduced precision in the head measurement for small values of H_a.

A best-fit analysis was performed on the "Montana" flume data (fig. 6) and resulted in equation 2 which is very similar to equation 1.

$$Q_{MONTANA}=0.06+4.09*H_a^{1.52}$$

Equation 2. Best fit equation for "Montana" Parshall flume (free flow only).

A small deviation between the best fit and standard equations was in constants "a" and "b". This difference resulted from the relatively large errors in low flow data. It should be noted that in all three data sets the degree of error was greatest for flows less than 2.0 ft³/s. In general, for flows greater than 2.0 ft³/s the error was within ±2-3 percent of the known discharge.

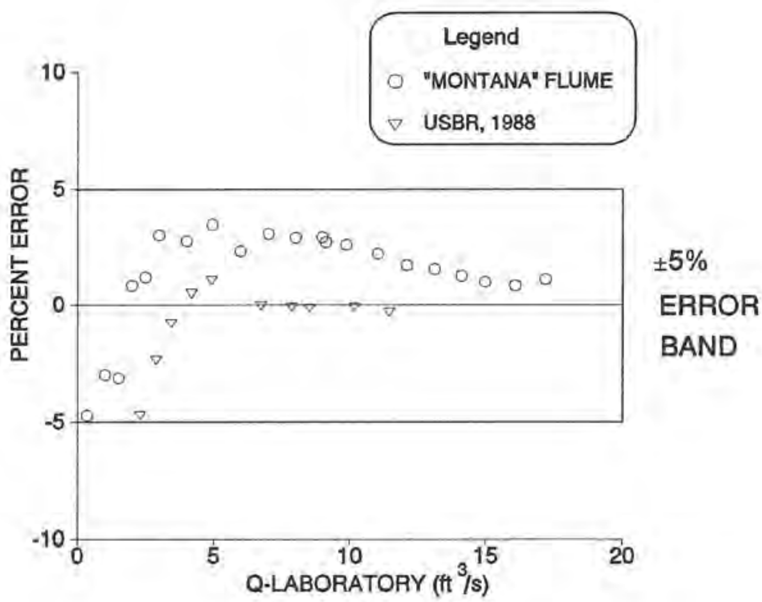


Figure 4. Percent error versus actual discharge (Q) for "Montana" and USBR Parshall flumes (H_a measured in stilling well).

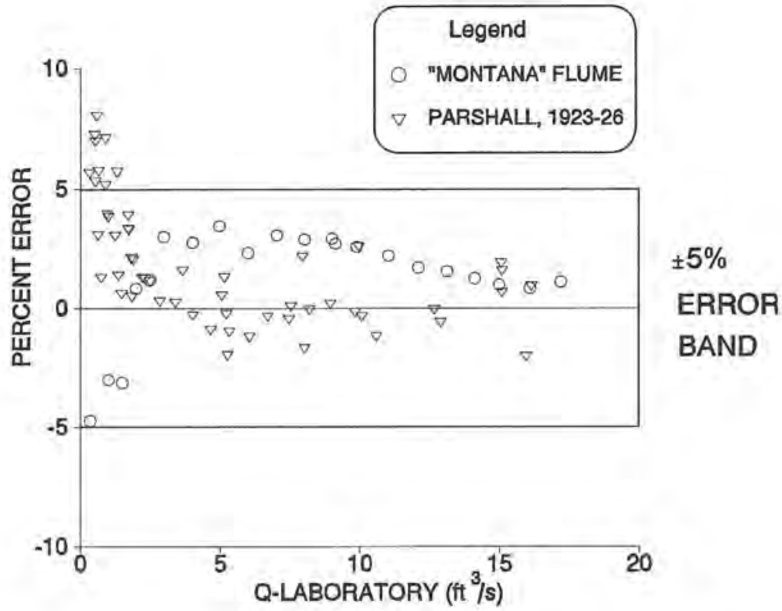


Figure 5. Percent error versus actual discharge (Q) for "Montana" and Parshall's original flume calibration (H_a measured in stilling well).

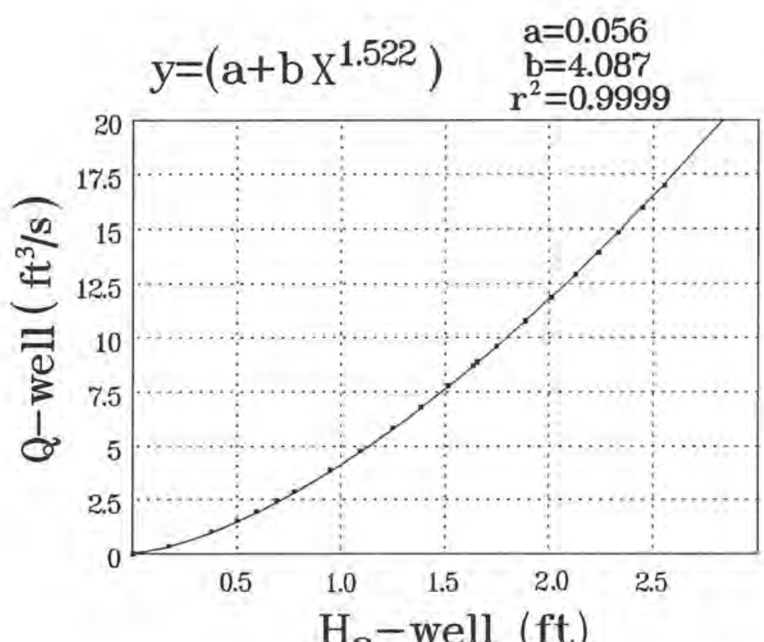


Figure 6. 1-ft "Montana" Parshall flume best-fit free flow equation.

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