10.2478/v10048-010-0019-1

Investigation on Application of Parshall Flume for Flow Measurement of Low-Flow Season in Korea

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The accurate determination of the flow rate of the low flow season is a very important factor in setting and running a water resources development plan. Because South Korea undergoes a lot of flood damage due to localized heavy rain during the summer season, flow rates are measured mostly according to flood management, and this allows for a lack in research in understanding low flow season flow rates. In order to estimate the accurate flow rate of a low flow season, the present study has used the Parshall flume that has been used widely in flow measurements, and has reviewed the applicability. A Parshall flume was installed in an actual river and the measured flow rate that was obtained from the flow rate formula and velocity measurements, that were suggested by the ISO and the USBR, were found to be very accurate when compared to the flow rate computation results by the Parshall flume. By using the state-discharge rating curve equation that is most commonly used at the level gauging station, the flow rate was estimated and compared with the flow rate by the Parshall flume. The results showed an approximate 14% error with the estimation from the state-discharge rating curve equation. Therefore, using the Parshall flume to estimate the flow rate of low flow season is more effective than the state-discharge rating curve equation.

Keywords: Parshall flume, low flow season, flow measurement, flow rate formula, state-discharge rating curve equation

1. INTRODUCTION

FLOW MEASUREMENTS take on a very important part in the water supply and watershed management of a river.

However, as flow measurements and water level measurements are run according to flood management, which means the June, July and August months in Korea, that take up 2/3 of the total precipitation amount, there are many problems during the low level season. Such problems include being unable to accurately estimate the inflow of a multi-purpose dam during droughts and therefore being unable to decide on the level of outflow, or having a river flow measurement whose precision is so low that the estimation of the amount of water resource credibility, which is the foundation to water allocation, is falling. In particular, low flow season flow rate influences the water supply, and this means that the scale of water resources development and managing is fully reflected and thus, accurate estimation is critical for a rational water resources development plan and its management [1].

Problems, such as the accuracy of low flow season estimations and the lack of consistency, can be solved to a certain extent by using structures such as a flume. There are different types of flumes, such as a cross section shape, or depending on the developer, a rectangular type flume, trapezoidal type flume, U-type flume, parabolic-type flume, circular type flue, long throated flume, SANIIRI flume and the Parshall flume.

In particular, the Parshall flume is a structure that changes the width of the sidewall, and makes the bottom higher so that a supercritical flow can occur easily, thus allowing sediment to enter and making the maintenance easy. This can be used not only in places where there are lots of sediments or a bed change, but this can be used to start a hydraulic jump within a structure, therefore making it possible to install in places where the bed slope does not have a high inclination. Also it has the ISO 9286 [2] verification and standardization by flow rate scale, which gains it credibility, and it is an environmentally friendly structure that does not block the path of fish without a separate fish way needed.

The Parshall flume was developed by R.L Parshall in 1922 and is installed in many American irrigation facilities. Peck [3] suggested the flow rate be based on the downstream water level of an aft Parshall flume of the USBR [4], and the USBR adjusted the flow rate formula that it had been using. The flow rate formula of the Parshall flume was suggested to the ISO 9826 [2] by different sizes, and therefore we can see that the tests and research on the flow rate formula of the Parshall flume has almost come to an end. Hirt et al. [5] used a 3 dimensional model that fixed the upstream water level of the Parshall flume to 0.8 ft and changed the downstream water level to free flow, submerged flow and fully submerged flow and estimated the flow rate based on these different categorizations. Gerrit and Adrianus [6] used the Parshall flume for sewage treatment, and were able to dissemble the grit from the sewage by maintaining a uniform velocity of the sewage.

This study analyzed the applicability of a structure such as the Parshall flume as a method for measuring flow rate of low flow seasons. In order to do this, a Parshall flume was installed in a river, the water gauge was determined and the flow rate was computed. The stage-discharge rating curve equation from the gauging station situated on the upstream was used to estimate the flow rate. The flow rate that was presented from the flow rate formula suggested by the ISO and the USBR, the measured flow rate obtained through velocity measurements, and the flow rate by stage-discharge rating curve equation were compared.

2. THE STUDY AREA AND THE PARSHALL FLUME

This study selected the Donghyang Parshall flume that has been installed in the Yongdam Dam region. The Donghyang Parshall flume is located at Longitude 127°32'31" and Latitude 35°49'43". The water gauging station (Longitude 127°32'48" and Latitude 35°49'49") is located 200 m upstream, thus making a favorable condition for analyzing the applicability of the Parshall flume. The Parshall flume and water gauging station are situated at Gu-Ryang-Chun – a stream of a watershed area of 165.2 km^2 and an average elevation of 640.38 *m* with a slope of 17.237%. Its width is approximately 90 meters; however, during its low flow season it measures approximately 50 meters. The bed material is composed of plume and gravel. Photo 1 shows the selected area, the Parshall flume, and the water gauging station.

Photo 1. Parshall flume, gauging station and catchment

The Parshall flume is standardized in various sizes and the measurements of the Parshall flume that were used in this study are shown in Fig.1.

The water depth measurement within the flume measures the contraction depth, H_a and the throat depth, H_b. In H_a , the 1/3 point of the length of the side wall at the starting point of the contraction is the water depth from the contraction bottom. In H_b, the water depth is 51 mm upstream from the lowest point of the throat and like H_a, it is the water depth from the contraction bottom.

The width of the throat of the flume is 1.524 meters; the range of flow rate measurement is 0.0441 m^3/sec ~2.424 m^3/sec; and the range of water level measurement is 0.06m~0.76m. When the submergence ratio (H_b /H_a) exceeds 0.7, the flow of the upper part of the stream from the Parshall flume gets disturbed, which diminishes the conveyance, thus the necessity for correction of flow rate arises. The study of this paper focuses on the flow rate measurement during the low flow season, thus it only measured H_a.

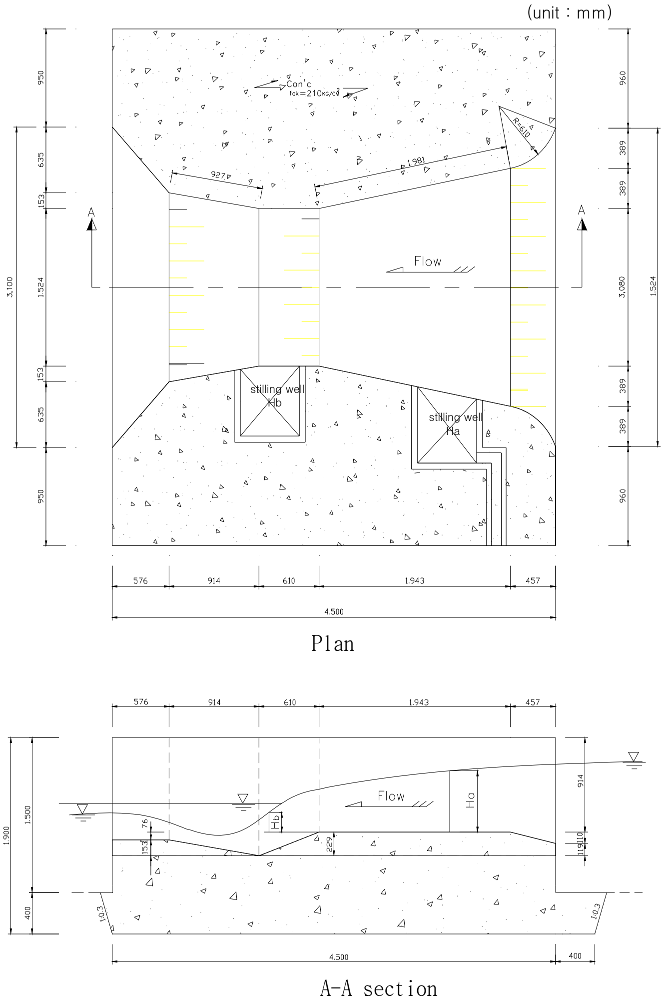

Fig.1. The designed Parshall flume

Table 1 The water depths measured at Donghyang Parshall flume

Date	Upstream of the structure water depth H_A (m)	Stilling well headwater depth H_a (m)
03/11/14 14:50	0.56	0.460
03/12/04 17:00	0.48	0.405
03/12/08 16:40	0.64	0.540
03/12/10 16:45	0.63	0.535
03?12/24 11:40	0.40	0.370

The basic principle of the Parshall flume is that when the water level is lower than the crest of the Parshall flume, the water level should be measured. The pre-measured water level should be substituted into the formula that converts water level into flow rate and then the flow rate is calculated. This study uses the bubble gauge to measure the water level. Table 1 presents the water depth upstream H_A of the Donghyang Parhsall flume that was measured 5 times in the field and the water depth H_a of the stilling well. However, a loss and fracture of the bubble pipe occurred due to the flood. There is a shortage of reliable data due to this problem.

3. Computation of Flow Rate

A. *Flow Rate by Parshall Flume Equation*

The size of the Donghyang Parshall flume is 5ft and the width of the throat is 1.524 *m* but at the ISO the standard that is closest to this structure is a 1.5 m Parshall flume. (1) that is presented by ISO allow so obtaining of the flow rate formula according to the width of the throat, and if the 1.524 *m* width of the throat is put into this equation, it can be expressed as (2).

$$Q = C_D b \left(\frac{H_a}{0.305} \right)^n \qquad (1)$$

$$Q = 3.7294 H_a^{1.5863} \qquad (2)$$

Where C_d is the coefficient of flow rate 0.372, b is the width of the throat, n is $1.569b^{0.026}$. Meanwhile the flow rate formula that is presented in the Water Measurement Manual [4] expresses the throat width of 1.524 *m* as (3).

$$Q = 20 H_a^{1.59} \qquad (3)$$

When there is a free flow, (2) and (3) become flow rate formulas. When there is a submerged flow, the flow rate of the free flow should be reduced. Because this study focuses on the low flow season, submerged flow is not taken into considera- tion. In (2) and (3) the H_a value of Table 1 is used to calculate the flow rate and this is shown in Table 2.

Table 2 The flow rates computed by Parshall flume equation

H_a	Flow rate(m^3/s)					
	ISO's formula			USBR's formula		
	H_a+1 cm	H_a	H_a-1 cm	H_a+1 cm	H_a	H_a-1 cm
0.370	0.804	0.770	0.738	0.804	0.771	0.738
0.405	0.924	0.889	0.855	0.925	0.890	0.855
0.460	1.126	1.088	1.051	1.128	1.090	1.052
0.535	1.424	1.383	1.342	1.427	1.385	1.344
0.540	1.445	1.403	1.362	1.448	1.406	1.365

The observation of water levels generally has an allowable error of ±1 *cm* [7]. Because the water depth of the Parshall flume, H_a, is measured while the water level is oscillating, there can be a ±1 *cm* error, and so this has also been calculated with in the flow rate and compared. Even though the flow rate that is calculated by using the formula presented by the ISO and the USBR is differently expressed, seeing as the difference is only 0~0.00 3m^3/s, we can agree that there is an almost identical flow rate. Also, the 1cm error of the water level causes a 0.034~0.042 m^3/s difference in flow rates, which means that this can cause a 3~4% error in flow rates.

Fig.2 illustrates the results from Table 2 and shows that the flow rates of both formulas are in close agreement.

B. *Flow Rate by Velocity Measurements*

In order to look at the accuracy of the flow rate formulas of the ISO and USBR, the flow velocity within the Parshall flume was measured and the flow rate was estimated. Due to the changes of the cross section of Parshall flume structures, the flow velocity fluctuation is high at each point, which means that when measuring flow rates within flumes using current meters, the measurements must be done very precisely.

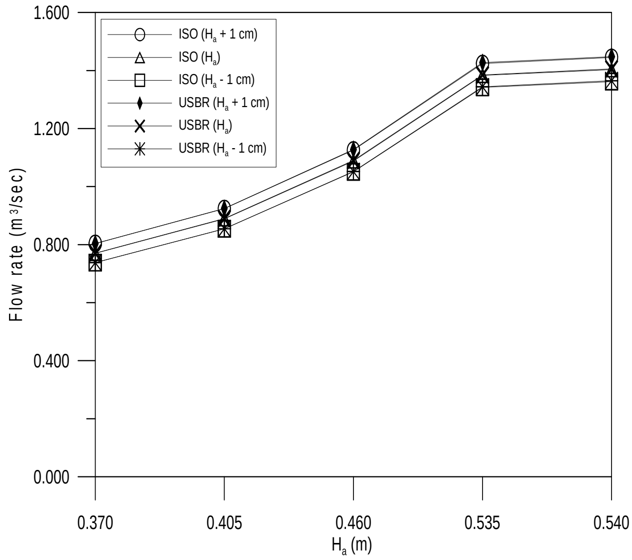

Fig.2. The comparison flow rates produced by Parshall flume equation.

This study measured the flow rate by a three point method that uses a rotating current meter with a 2 *cm* diameter rotating fan while maintaining a 0.1 *m* current line interval. The water depth at the time of measurement was 0.44 *m* and the flow rate was 1.008 m^3/s. The result by flow rate formula and the result by flow rate measurements are expressed in Table 3. As the results show, the measured flow rate and the calculated flow rate by the flow rate formula were in good agreement. Therefore, this shows that the Parshall flume flow rate formula has a very good accuracy.

Table 3 The comparison of the flow rate between Parshall flume equation and the flow measurement

H_a (m)	Flow rate (m^3/s)		
	ISO's formula	USBR's formula	Flow measurement
0.440	1.014	1.015	1.008

C. Flow Rate by Rating Curve

The Donghyang Parshall flume is installed at 200 *m* in a straight upstream. The gauging station carries out flow rate measurements every year. In between the place where the Donghyang Parshall flume and the gauging station were installed, there is no confluence or divergence which gives favorable conditions for comparing flow rate estimation results.

Table 4 Rating curve of Donghyang station

Index	Rating curve	Range	R2
Total 2003	$Q = 12.834 \times (H - 1.565)^{3.080}$	Full range	0.988
	$Q = 12.418 \times (H - 1.557)^{3.107}$	H < 2.33	0.975
	$Q = 20.653 \times (H - 1.711)^{2.732}$	H≥2.33	0.986
Before Flood 2003	$Q = 34.224 \times (H - 1.918)^{2.415}$	Full range	0.994
	$Q = 36.373 \times (H - 1.930)^{2.398}$	H<2.82	0.991
	$Q = 19.808 \times (H - 1.694)^{2.757}$	H≥2.82	0.986
After Flood 2003	$Q = 12.901 \times (H - 1.550)^{3.026}$	Full range	0.997
	$Q = 11.572 \times (H - 1.524)^{3.101}$	H<2.67	0.989
	$Q = 26.592 \times (H - 1.816)^{2.597}$	H≥2.67	0.998

In 2003 there were 68 flow rate measurements taken at the Donghyang gauging station. The results of the flow rate measurements were analyzed so that the stage-discharge rating curve equation of gauging station could be derived [8]. However, typhoon Mae-Mi (September, 2003) caused changes in the cross section of the river through the flood, and so we categorized the water measurement data according to the entire period (2003), before, and after the flood, and induced the water rating curve equation accordingly.

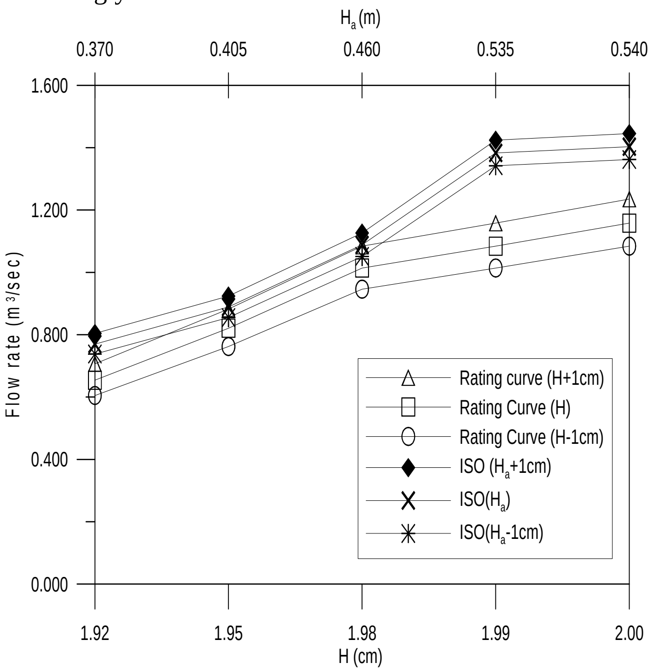

Fig.3 The comparison of flow rates produced by rating curve and ISO formula

Table 4 shows the flow rate calculations using the stage-discharge rating curve equation of the gauging station. Water level *H*, which applies the stage-discharge rating curve equation, is the Donghyang gauging station's water level when measuring the water depth H_a from the stilling well of the Parshall flume. Table 5 shows the flow rate measurements for the measured error ±1 *cm* (n). Fig.3 illustrates the results of Table 5. The discharge of the Parshall flume in Fig.3 is computed according to the ISO formula.

We discovered that a difference of 1 cm in the water level in the Parshall flume demonstrated a difference of 0.034~0.042 m^3/sec in the discharge, which caused an error of 3-4%; in comparison, a 1centimeter difference in the equation showed a difference of 0.049~0.077 m^3/sec in the discharge and thus caused an error of 5-8%.

Table 5 The flow rates computed by rating curve

H (m)	H_a (m)	Rating curve	Flow rate(m^3/s)		
			H +1 cm	*H*	*H* -1 cm
1.920	0.370	$Q = 11.572 \times (H - 1.524)^{3.101}$ $H < 2.67$	0.707	0.654	0.605
1.950	0.405		0.882	0.821	0.762
1.980	0.460		1.084	1.014	0.946
1.990	0.535		1.158	1.084	1.014
2.000	0.540		1.235	1.158	1.084

4. Results and Discussion

When compared to the measured flow rate by flow velocity, the flow rate computed by Parshall flume's flow rate formula possessed higher accuracy. Table 6 shows the comparison made between the flow rate formula and the flow rate calculated by the stage-discharge rating curve equation. Fig.4 illustrates the results of Table 5.

As we can see from Table 2, Table 5, and Fig.4, the flow rate by the stage-discharge rating curve equation was not included within the section of flow rate by ISO and USBR formula, which considered up to a ±1 *cm* measurement error, and was shown in 14% of small value.

Due to the ISO/TR5168, when the flow rate was measured by current meter and flume at the 95% level of credibility, the uncertainty of results that could occur was 5%. Therefore, the flow rate calculated by the stage-discharge rating curve equation could be seen as a lot less reliable.

Table 6 The flow rates computed by Parshall flume equation and rating curve

H (m)	H_a (m)	Flow rate (m^3/s)			(1)-(3)	(2)-(3)
		ISO's formula (1)	USBR's formula (2)	Rating curve (3)		
1.920	0.370	0.770	0.771	0.654	0.116	0.117
1.950	0.405	0.889	0.890	0.821	0.068	0.069
1.980	0.460	1.088	1.090	1.014	0.074	0.076
1.990	0.535	1.383	1.385	1.084	0.299	0.301
2.000	0.540	1.403	1.406	1.158	0.245	0.248

5. Conclusions

Flow measurements take on a very important part in the water supply and watershed management of a river. However, because flow measurements are run according to flood management, which means the June, July and August months in Korea, that take up 2/3 of the total precipitation amount, there are many problms during the low level season.

Because the low flow season flow rate influences the scale of water resources development, accurate estimation is essential.

In order to estimate the accurate flow rate of a low flow season, the present study has used the Parshall flume, and has reviewed the applicability.

The calculated flow rate by the Parshall flume flow rate formula showed similar results to the measured flow rate. Therefore, this showed that the flow rate calculated by the Parshall flume had a very high accuracy.

By using the state-discharge rating curve equation that is most commonly used at the level gauging station, the flow rate was estimated and compared with the flow rate by Parshall flume. The flow rate formula based on the state-discharge rating curve equation reslts showed an approximate 14% error.

Because the low flow rate calculation by the state-discharge rating curve equation had a greater error than the Parshall flume, in order to calculate the accurate low flow rate, the flow rate measurement by Parshall flume should be expanded.

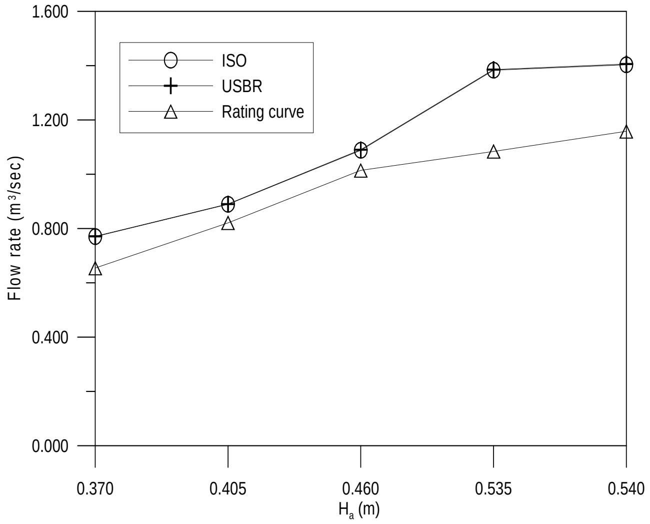

Fig.4. The comparison of flow rates computed by Parshall flume equation and rating curve.

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Received April 7, 2010.
Accepted October 18, 2010.