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RESEARCH ARTICLE

Parshall Flume Discharge Relation under Free Flow Condition

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Abstract

Parshall flumes are well accepted and extensively used for management of water used in irrigation. In the present study experimental work has been carried out on Parshall flumes having throat width of 0.052 m, 0.076 m, 0.152 m and 0.229 m under free flow condition. Coefficient of Parshall flume (K) and exponent (n) were determined through MATLAB programming and a unique discharge rating equation has been developed for Parshall flumes. This equation is simple and can be applied for field condition.

Introduction

One of the important problems in irrigation system is measurement of irrigation water that flows in small channels. Several devices have been used for measuring irrigation water including weir, Venturi flume, Cutthroat flume, Parshall flumes, etc. However, Parshall flume is one of the effective flow measuring devices for small irrigation channels. Parshall flumes can measure discharges with comparatively small head loss with low head than weirs. There is one more advantage of Parshall flume is that it can operate successfully with sediment laden flow. A Parshall flume consists of a converging section, a throat section and diverging section [10]. The crest of the throat section is tilted downstream. In other words, there is a sill between the horizontal crest, converging section and the crest of the throat section. Fig. 1 depicts the schematic diagram of a Parshall flume. Upstream head (h) was measured at specific location (Fig.1). Under free-flow condition, the flow at on upstream division will be subcritical while it becomes critical at around the throat and finally may become supercritical at the downstream portion of the flume. Hence for a Parshall flume, a unique relation must be present between the discharge and the head causing flow. Calibration of the flume in field is difficult in most of the cases. Therefore it is required to develop a relationship between head and discharge to calibrate flumes in the field.

In 1917, Cone [6] developed a flume which is working on Venturi principle of flow applied in open channel and known as Venturi flume. He carried out experimental work in the small flumes and resulted with that the Venturi flume seems to fulfil the conditions of being trouble free from sand, silt, or floating trash and requires small loss of head for making the measurement. In 1928, Parshall [10] modify the Venturi flume by reducing the angle of convergence and divergence section, providing depression on throat section towards diverging section along with increase length of throat. In his study he tested Parshall flumes varying 1 foot to 8 feet. Parshall express discharge relation for free flow condition by following expression [10].

$$Q = J\ H^{n} \qquad (1)$$

With J = 4W and n = 1.55 W $^{0.0026}$, thus the equation (1) is written as follows

$$Q= 4WHa^{1.522\ W^{0.026}} \tag{2}$$

In equation (2), Q is the discharge in ft^3/s, W is the throat width in feet and Ha is the upstream head measured at 2/3 of the convergence section in feet. He found that Parshall flume is working efficiently and head loss is four times lesser than weir. In 1967, Skogerboe et al. [12] studied the parameters which describe submergence in flow measuring flumes and it was developed by a combination of dimensional analysis. Validity of the parameters was verified by the theoretical submerged flow equation developed from momentum relationships.

In 1990, Abt and Staker [1] attempted experiment for a 7.62-cm Parshall flume in a channel and measure flow rates with lateral flume crest slopes of 0, 3.6, 6.5, 9.0, 13.3, -3.8, -4.8, -7.2, and -11.8%. The results of this study showed that the Parshall flume has error approximately 7% at a lateral slope of ±10%. In 1994, Blaisdell [3] conducted an experiment with different size of Parshall flumes and analysis of results with Parshall's experiment data was carried out. Study resulted with conclusion that equation given by Parshall and these investigators have same accuracy within practical limit. In 2009, Thornton et al. [13] conducted an experiment for 15 different Parshall Flume configurations. They found in this study that single Parshall flume can be used to measure flow within ±5% accuracy for both supercritical and subcritical flow regimes for a specified range of flows.

A single relation between discharge and upstream head is not available in literature. The objective of present study is to develop a single relation between discharge and upstream head for different throat width Parshall flumes under free flow condition. With this objectives experiment work was carried out on four Parshall flumes having throat width of 0.052 m, 0.076 m, 0.152 m and 0.229 m.

MATERIAL AND METHODS

In present study, four different sizes of Parshall flumes having throat width of 0.052 m, 0.076 m, 0.152 m and 0.229 m were used. The dimensions of Parshall flume used in this study are given in Table 1. The flumes were installed in a flat bed recirculatary rectangular channel having a size of 9.45 m × 0.60 m × 0.55 m at Fluid Mechanics Laboratory of Maulana Azad National Institute of Technology, Bhopal. Fig.2 depicts the schematic diagram of experimental setup. It shows that Parshall flumes were installed in a rectangular channel. The water supply was done by a centrifugal pump to the channel which delivered water from sump to channel. The heads at the upstream location was measured by a vernier type pointer gauge with an accuracy of ±1 mm and velocity was measured using Prandtl Pitot tube. The discharge is calculated by velocity area method. The values of measured heads and discharges are given in Appendix A.

In free-flow condition, discharge through Parshall flume depends on upstream head at a specific position (Fig.1) of the Parshall flume. Hence, discharge can be expressed as:

$$Q = f\,(h, W, g) \tag{3}$$

$$Q = C_d \sqrt{2g}\ W\ h^n \tag{4}$$

$$Q = K h^n \quad \text{where } (K = C_d \sqrt{2g}\ W) \tag{5}$$

Where Q is the discharge through Parshall flume, W is the throat width of the Parshall flume, K is the coefficient of Parshall flume which is the function of throat width, h is the upstream head measured at 2/3 of convergence section , n is the exponent of h and g is acceleration due to gravity.

Equation (5) can be normalized by taking logarithmic both sides.

$$Log_{10}\ Q = Log_{10}\ (K h^{n}) \tag{6}$$

$$Log_{10}\ Q = Log_{10}\ K + n\ Log_{10}\ h \tag{7}$$

If $Log_{10}\ Q = Y$, $Log_{10} K = A$ and $Log_{10}\ h = X$ than Equation (7) can be written as

$$Y = A + n X \tag{8}$$

DISCHARGE RELATIONSHIP FOR SMALL PARSHALL FLUMES

Observations for discharges and heads on four Parshall Flume of different sizes are made. All 37 observations are given in Appendix A. Regression analyses for all these observations were performed for mathematical relations given by equation (8). The values of coefficients K, exponent n and coefficient of determination R^2 for all these equations are given in Table 2. With these values equation (5) can be written for different flume as:

For 0.052 m Parshall flume, $Q_r = 0.147\, h^{1.512}$ (9)

For 0.076 m Parshall flume, $Q_r = 0.227\, h^{1.531}$ (10)

For 0.152 m Parshall flume, $Q_r = 0.397\, h^{1.640}$ (11)

For 0.229 m Parshall flume $Q_r = 0.571\, h^{1.587}$ (12)

Table 2 shows that equation (9) developed with R^2 = 0.995, 0.673, 0.984 and 0.968 respectively for equation (10), (11) and (12). It also shows that exponent n varies from 1.512 to 1.640. Relationship between actual discharge and corresponding head was shown in fig. 3.

DEVELOPEMENT OF UNIFIED EQUATION FOR SMALL PARSHALL FLUMES

In 1928, Parshall [10] had correlate the coefficient of Parshall flume (J) with the function of throat width, W (J = 4W) in fps system. On the similar line, present analysis has been carried out, in which J = K = 2.78 W for 0.052 m and 0.076 m Parshall flumes. The value of K = 2.78 W is obtained by hit and trial to match with the experimental value of K. It is found that the computed value of K and through hit and trial are more or less same (Table 3). Similarly J = K = 2.50 for 0.152 m and 0.229 m Parshall flumes (Table 4). The corresponding value of exponent n kept as 1.5 and 1.55 respectively. These values of ‘K’ and ‘n’ are given in Table 3 and Table 4.

From Table 3 and Table 4, equation (5) can be written as

$$Q_p = 2.78\, W\, h^{1.5} \tag{13}$$

$$Q_p = 2.50\, W\, h^{1.55} \tag{14}$$

The experimental data were plotted in Fig. 4 along with the fitted equation 13 and equation 14. Fig. 4 shows a good agreement of experimental data with the fitted equations. Now considering the average value of K as 2.72 W and keeping n = 1.55, after dividing by W, a curve was plotted in Fig. 5, which shows the variation of discharge intensity.

$$Q_p = 2.72 W\, h^{1.55} \tag{15}$$

COMPARISON OF EXPERIMENTAL DATA WITH USDA METHOD

In order to compare the accuracy of equation 15 with the discharge calculated by USDA, the comparison discharge calculated by Equation 15 and discharge calculated by USDA is shown in Fig. 7. It is clear from fig.8, the proposed equation established as compare to USDA within ±10 % error.

CONCLUSIONS

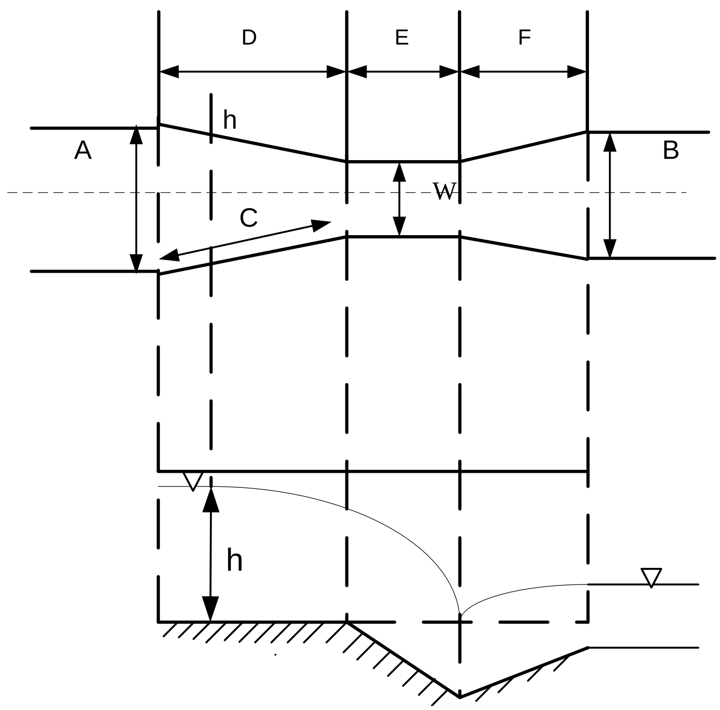

Fig. 1: Plan and Sectional view of Parshall Flume

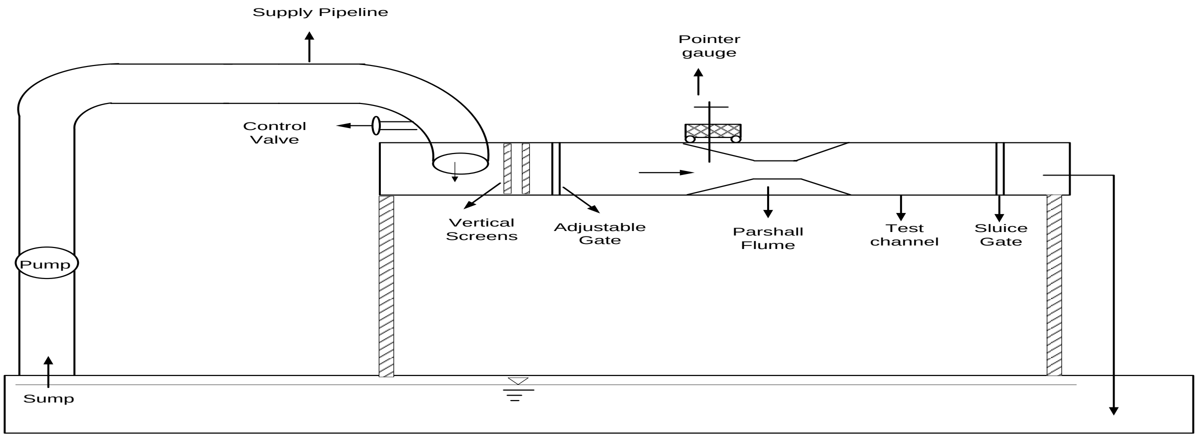

Fig.2: Schematic diagram of Experimental Setup

Table 1: Dimensions of Parshall Flumes used in Experiments (All dimensions are in meter)

W	A	B	C	D	E	F
0.052	0.215	0.135	0.413	0.404	0.114	0.254
0.076	0.472	0.178	0.466	0.457	0.152	0.305
0.152	0.397	0.387	0.621	0.609	0.305	0.609
0.229	0.575	0.391	0.879	0.864	0.305	0.457

Table 2: Regression analysis of Experimental data

W , meter	K	n	R^2
0.052	0.147	1.512	0.995
0.076	0.227	1.531	0.673
0.152	0.397	1.640	0.984
0.229	0.571	1.587	0.968

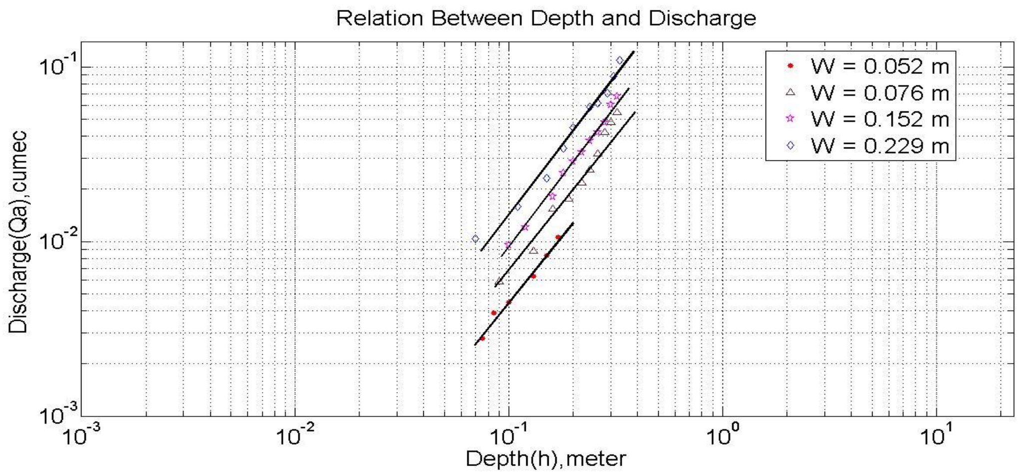

Fig. 3: Relationship between Actual discharge and upstream head for Parshall flumes.

Table 3: Coefficient of Parshall flume and Exponent for Proposed equation

Throat width, W	Coefficient of Parshall flume , K		Exponent , n		R^2
	experimental	2.78 W	experimental	n	
0.052 m	0.147	0.144	1.512	1.50	0.987
0.076 m	0.227	0.221	1.531	1.50	0.732

Table 4: Coefficient of Parshall flume and Exponent for Proposed equation

Throat width, W	Coefficient of Parshall flume , K		Exponent , n		R^2
	experimental	2.50 W	experimental	n	
0.152 m	0.397	0.380	1.640	1.55	0.965
0.229 m	0.571	0.572	1.587	1.55	0.889

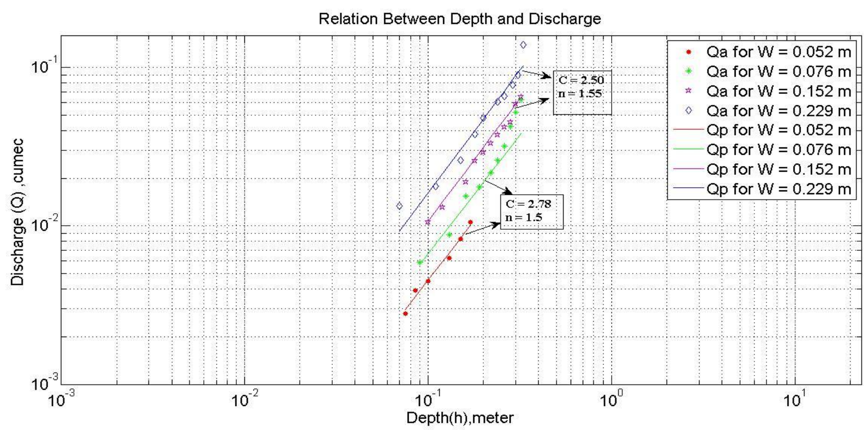

Fig. 4: Relationship between discharge – depth for Parshall flumes

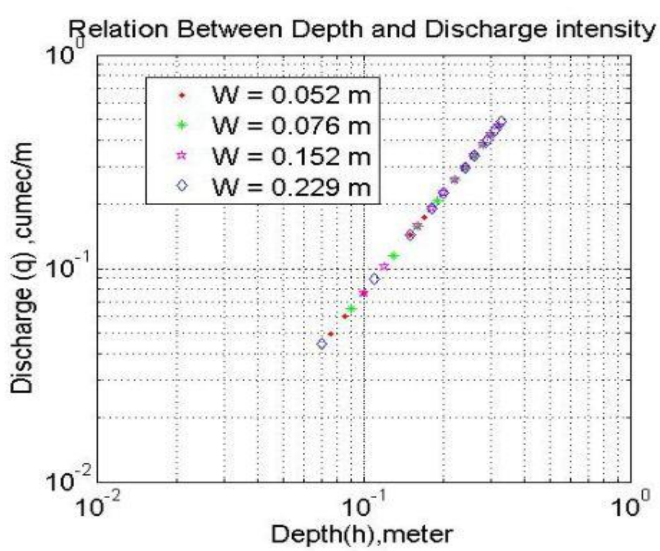

Fig. 5: Relationship between discharge intensity and upstream depth for Parshall flumes

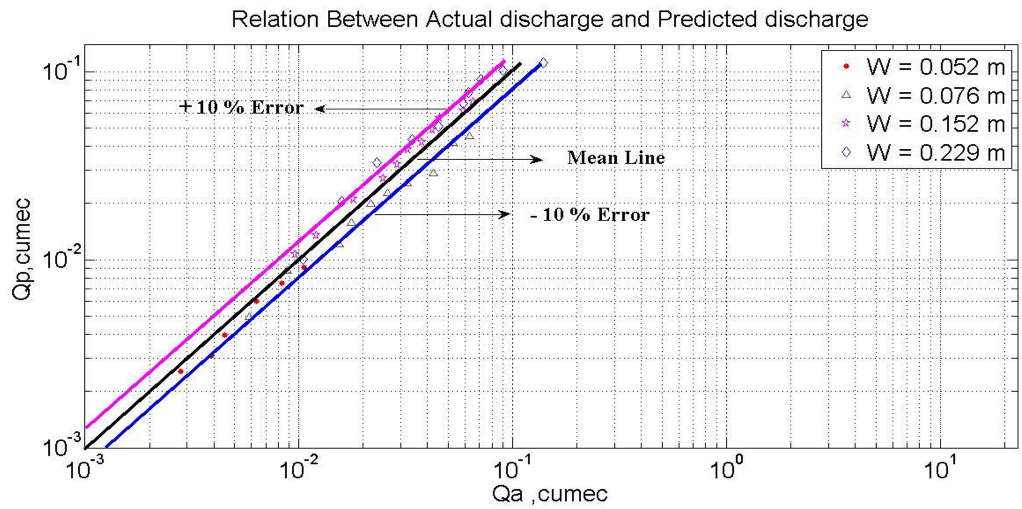

Fig.6: Relationship between actual discharge and Predicted discharge for Parshall flumes

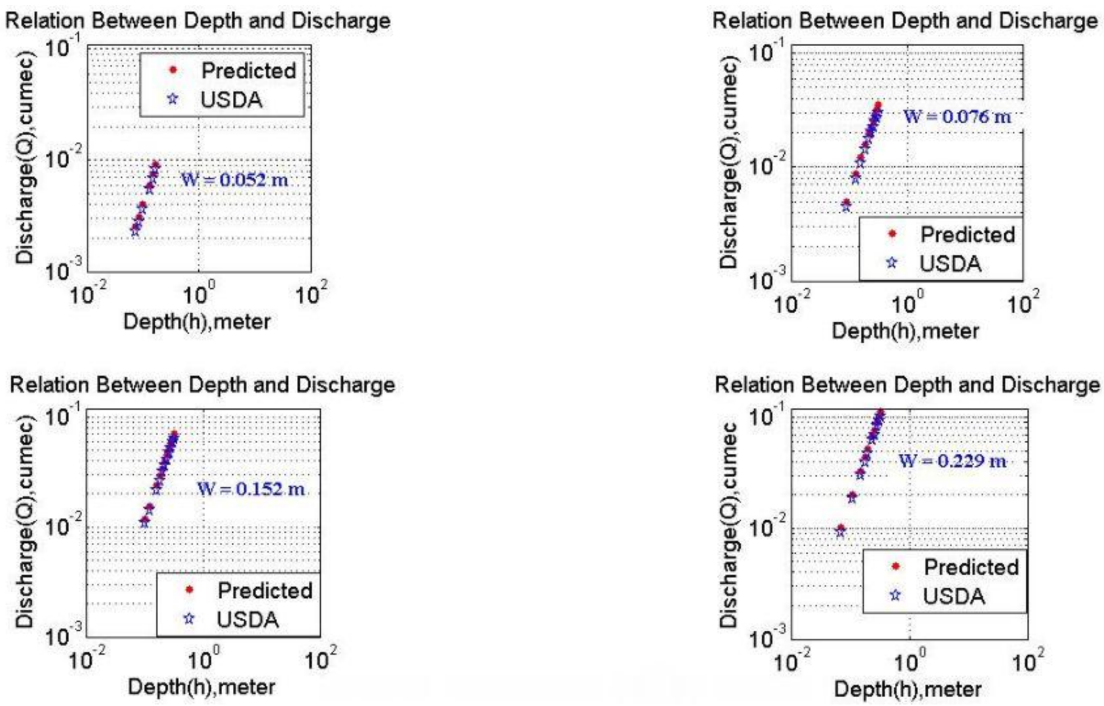

Fig.7: Comparison of discharge calculated by USDA and Predicted discharge for Parshall flumes

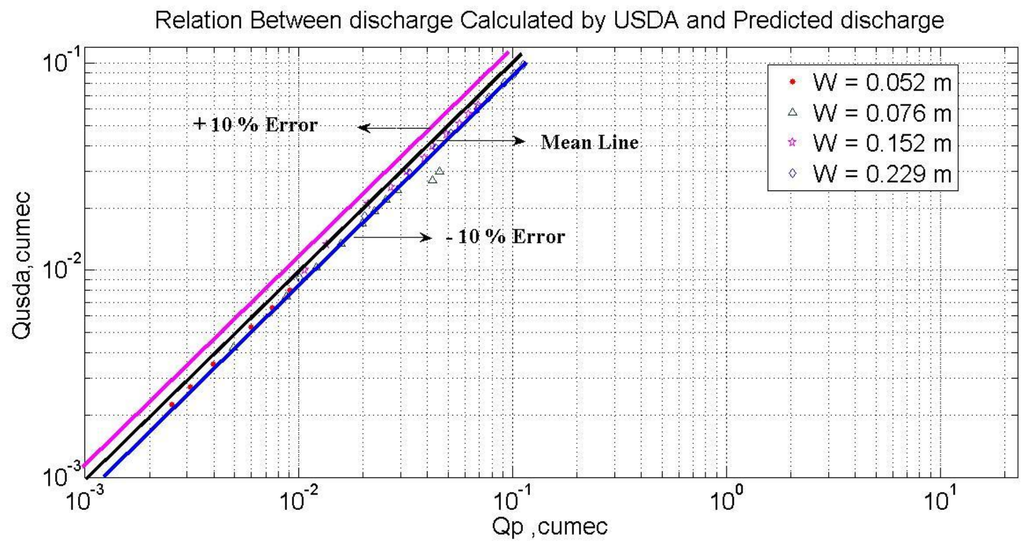

Fig. 8: Relationship of discharge calculated by USDA and Predicted discharge for Parshall flumes

Based on experimental work carried out, following conclusions are drawn:

A universal relationship of discharge and head is not available in literature for the small Parshall flume having throat width up to 0.229 m. Such a relationship is necessary for the measurement of less discharge in field condition. With this concept, a semi-empirical formula has been developed as given as below:

$$Q_p = 2.72\, W h^{1.55}$$

From experimental results and proposed equation (15) the introduced is within ± 10 %. It is also concluded that results obtained using Eq. (15) and USDA equations; the error is within ± 10 %

APPENDIX A: Free Flow Observations for Parshall Flumes

Throat width ,W	Test	Upstream Head, (h) , m	Actual discharge,(Qa), m^3/s
0.052 m	1	0.075	0.0028
	2	0.085	0.0039
	3	0.100	0.0045
	4	0.130	0.0063
	5	0.150	0.0083
	6	0.170	0.0106
0.076 m	1	0.09	0.0059
	2	0.13	0.0088
	3	0.16	0.0154
	4	0.19	0.0175
	5	0.22	0.0217
	6	0.24	0.0259
	7	0.26	0.0320
	8	0.28	0.0424
	9	0.30	0.0524
	10	0.32	0.0625
0.152 m	1	0.10	0.0096
	2	0.12	0.0121
	3	0.16	0.0180

	4	0.18	0.0247
	5	0.20	0.0289
	6	0.22	0.0324
	7	0.24	0.0377
	8	0.26	0.0421
	9	0.28	0.0453
	10	0.30	0.0587
	11	0.32	0.0651
0.229 m	1	0.07	0.0104
	2	0.11	0.0158
	3	0.15	0.0231
	4	0.18	0.0340
	5	0.20	0.0449
	6	0.24	0.0589
	7	0.26	0.0619
	8	0.29	0.0711
	9	0.31	0.0898
	10	0.33	0.1398

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