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Laboratory Investigations of Submerged Flow in Selected Parshall Flumes

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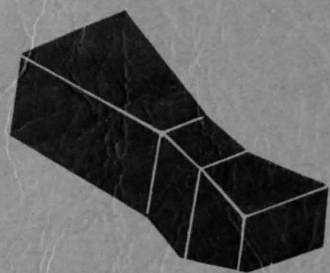
LABORATORY INVESTIGATIONS OF SUBMERGED FLOW IN SELECTED PARSHALL FLUMES



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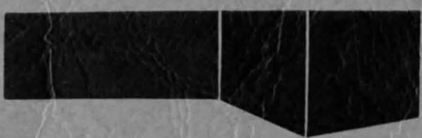

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah

January 1966

Report PR-WR6-6

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NOMENCLATURE

Symbol	Definition
H_a	Depth of flow in a Parshall flume measured in the converging inlet section at a point two-thirds the length of the entrance section upstream from the flume crest, ft.
H_b	Depth of flow in a Parshall flume measured at a particular referenced point in the throat, ft.
Q	Actual discharge, cfs.
W	Throat width of a Parshall flume, ft.

PURPOSE OF STUDY

The primary objective of this study was to ascertain from selected sizes of Parshall flumes further proof of the validity of the method of analyzing submerged flow developed at Utah State University. The flume sizes selected for study were the standard 6-inch, 1-, 4-, and 6-foot Parshall flumes.

The data of Parshall (1953) was subjected to this method of analyzing submerged flow by Skogerboe, Hyatt, England, Johnson, and Griffin (1965). From this analysis the submerged flow calibration curves were developed for the sizes of Parshall flumes mentioned above. However, the authors desire to supplement this work with data collected in the laboratory and other selected sources for further validity of the calibration curves which were previously developed using Parshall's data.

Data was collected at the Utah Water Research Laboratory for the 1- and 4-foot flumes; the data of F. W. Blaisdell (1944) was used for the 6-foot flume; and the data of V. N. Gunaji (1950) was utilized for the analysis of the 6-inch flume. The resulting equations and calibration curves are listed in this report.

Since this study has been made only to provide supplemental information on the submerged flow calibration curves of the 6-inch, 1-, 4-, and 6-foot Parshall flumes, such items as construction, setting, maintenance, and methods for measurements are not considered in this report. The authors feel the work by Parshall (1953) is very adequate on these topics and should be referred to by the reader.

Figure 1 is a plan and sectional view of a typical Parshall flume, along with a letter for each dimension line. Listed in Table 1 are the values of each dimension for the selected sizes of flumes. The size of flume is denoted by its throat-width, designated as W in Table 1. Also shown in Table 1 is the approximate discharge capacity of each flume, and the location of the flow depth measurement points, H_a and H_b.

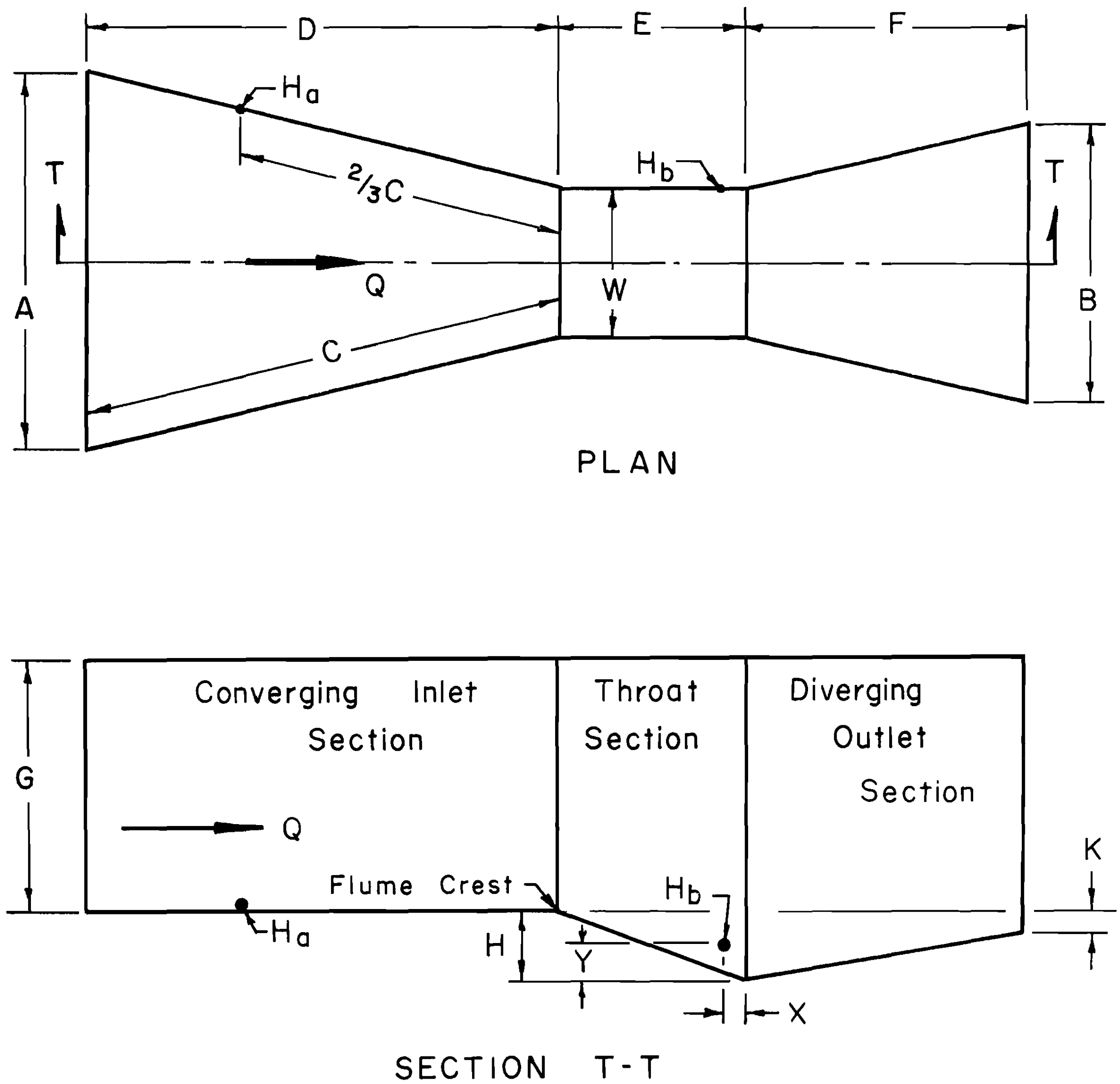

Figure 1. Plan and sectional view of Parshall measuring flumes.

Table 1. Dimensions and capacities of selected Parshall flumes.

Throat Width W	Dimensions in Feet and Inches												Free Flow Capacities	
ft. in.	A	B	C	2/3 C	D	E	F	G	H	K	X	Y	Min. cfs	Max. cfs
0' 6"	1' 3.50"	1' 3.5"	2' 0.44"	1' 4.31"	2' 0.00"	1' 0"	2' 0"	1' 6"	4.5"	3"	2"	3"	0.05	2.9
1' 0"	2' 9.25"	2' 0.0"	4' 6.00"	3' 0.00"	4' 4.88"	2' 0"	3' 0"	3' 0"	9.0"	3"	2"	3"	0.40	16.0
4' 0"	6' 4.25"	5' 0.0"	6' 0.00"	4' 0.00"	5' 10.63"	2' 0"	3' 0"	3' 0"	9.0"	3"	2"	3"	1.30	68.0
6' 0"	8' 9.00"	7' 0.0"	7' 0.00"	4' 8.00"	6' 10.38"	2' 0"	3' 0"	3' 0"	9.0"	3"	2"	3"	2.60	104.0

CHARACTERISTICS OF SUBMERGED FLOW

Many measurement structures utilize the principle of passing the flow through critical depth. When the flow passes through critical depth then free flow conditions exist and the discharge is dependent upon only the upstream depth of flow. However, when the downstream depth of flow increases to the point that the upstream depth of flow is affected then free flow conditions no longer exist and the flow is said to be submerged. Submergence, which is often expressed as a percentage, is the ratio of the downstream head of a flume to the upstream head. In a Parshall flume the downstream head, H_b, is the depth of flow measured at a particular referenced point in the throat, whereas the upstream head, H_a, is the depth of flow located two-thirds of the length of the converging entrance section upstream from the flume crest. Hence, submerged flow conditions exist in a Parshall flume when the depth of flow at H_b becomes great enough to affect the upstream depth of flow, H_a. When submerged flow conditions exist, the stage-discharge relationship developed for free flow conditions is no longer valid and another method for analyzing the flow must be used.

Previously, the principal method used for analyzing submerged flow has been to apply a correction to the free flow discharge with the higher submergence values requiring higher corrections. However, another method of analyzing the submerged flow problem has been reported by Hyatt (1965) in a thesis conducted under the supervision of

SIX-INCH PARSHALL FLUME

Analysis of data

The data used for the analysis of the 6-inch Parshall flume was taken from a study by Gunaji (1950). The large amount of data furnished by this study was felt to be sufficient to verify the method of analyzing submerged flow as previously explained.

The first and most vital step in the analysis was the determination of the power of the $H_a - H_b$ term, or the slope of the lines of constant submergence. Skogerboe, Hyatt, Johnson, and England (1965) have shown that the value of the power of $H_a - H_b$ in the submerged flow equation and the power of H_a in the free flow equation are the same for any given flume. The power of H_a in the free flow equation is obtained more easily and has been made available by Parshall (1953). For the 6-inch flume Parshall gives the value of the H_a power as 1.58. Villemonte and Gunaji (1953) give the power as 1.57. Because of the small difference in the two, and the more common acceptance of the work of Parshall, the value of 1.58 was selected. Thus the free flow equation for the 6-inch Parshall flume as given by Parshall (1953) is

$$Q = 2.06 H_a^{1.58} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 1$$

Next the data was plotted on a three-dimensional log-log plot with Q plotted as the ordinate, $H_a - H_b$ as the abscissa, and H_b/H_a as the varying parameter (Figure 2). As shown in Figure 2, the slope of 1.58, the same slope as the free flow equation, is the slope which best fits the submerged flow data. Hence, the dashed lines of constant

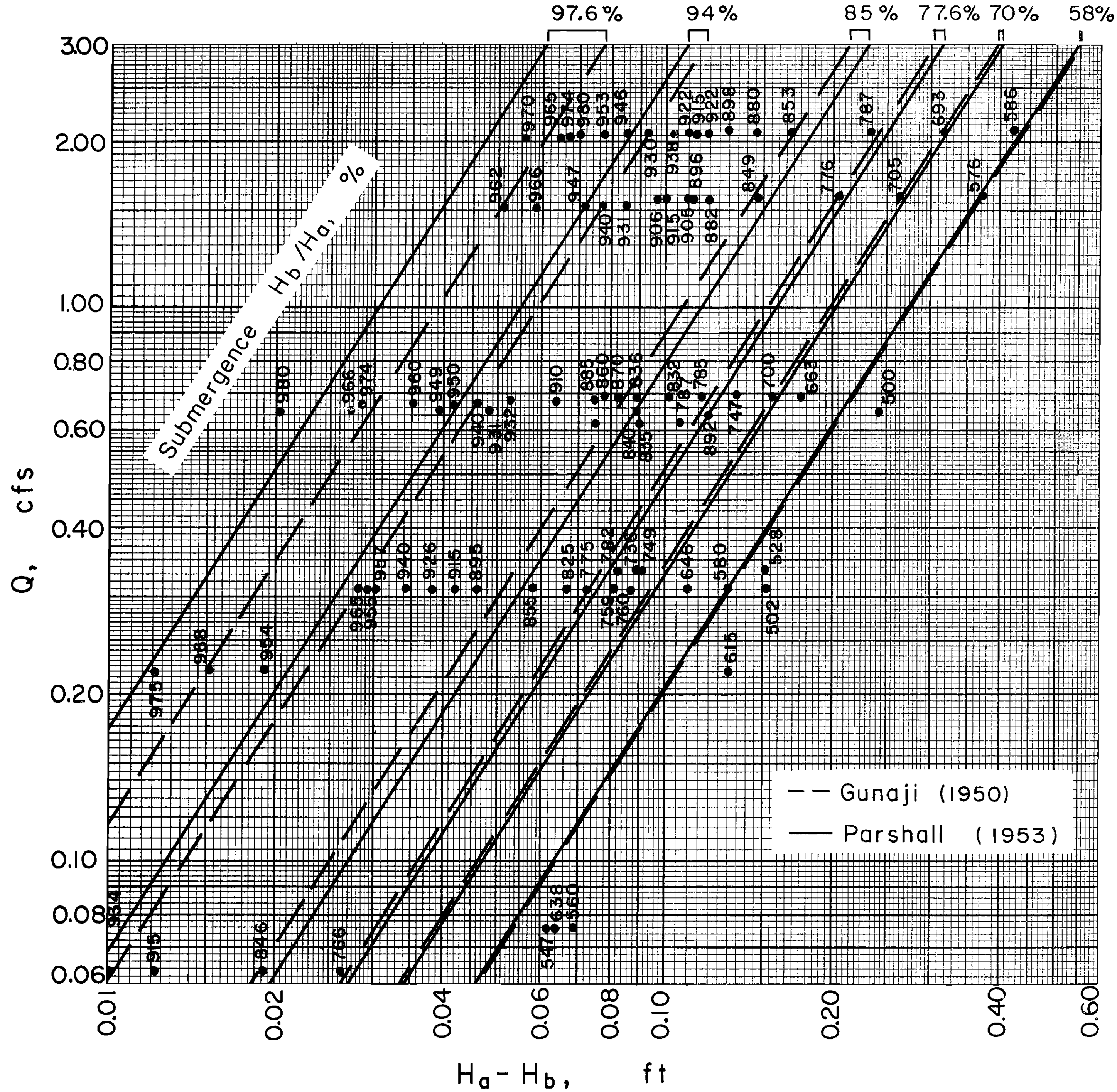

Figure 2. Plot of 6-inch Parshall flume submerged flow data.

submergence which best fit the data of Gunaji (1950) are drawn on the slope of 1.58.

Villemonte and Gunaji (1953) in their study of the 6-inch Parshall flume state the upstream depth is unaffected until a submergence of about 56 percent is reached. Also, stated at a submergence of about 90 percent--designated as the "critical submergence"--in the diverging section of the flume a strong, backward rolling hydraulic jump in the flow changes to essentially standing waves. The scatter in the data of Figure 2 between the submergence values of 86 percent and 94 percent indicates the change in the flow described by Villemonte and Gunaji (1953).

The solid lines of constant submergence in Figure 2 are drawn to fit the submerged flow data of Parshall (1953). The solid lines have the same value of submergence as the dashed lines which are drawn to fit the data of Gunaji (1950). As illustrated in Figure 2, the 58, 70.0, and 77.6 percent solid and dashed submergence lines are almost identical. The 85, 94, and 96.7 percent dashed submergence lines, which bracket the "critical submergence" of Villemonte and Gunaji (1953), have poor compatibility with the solid submergence lines developed from the data of Parshall. Other tests conducted by the authors regarding Parshall flumes are also incompatible with the data of Gunaji at these higher submergence values. Using the data of Parshall (1953) the submerged flow calibration curves for the 6-inch Parshall flume are obtained as shown in Figure 3.

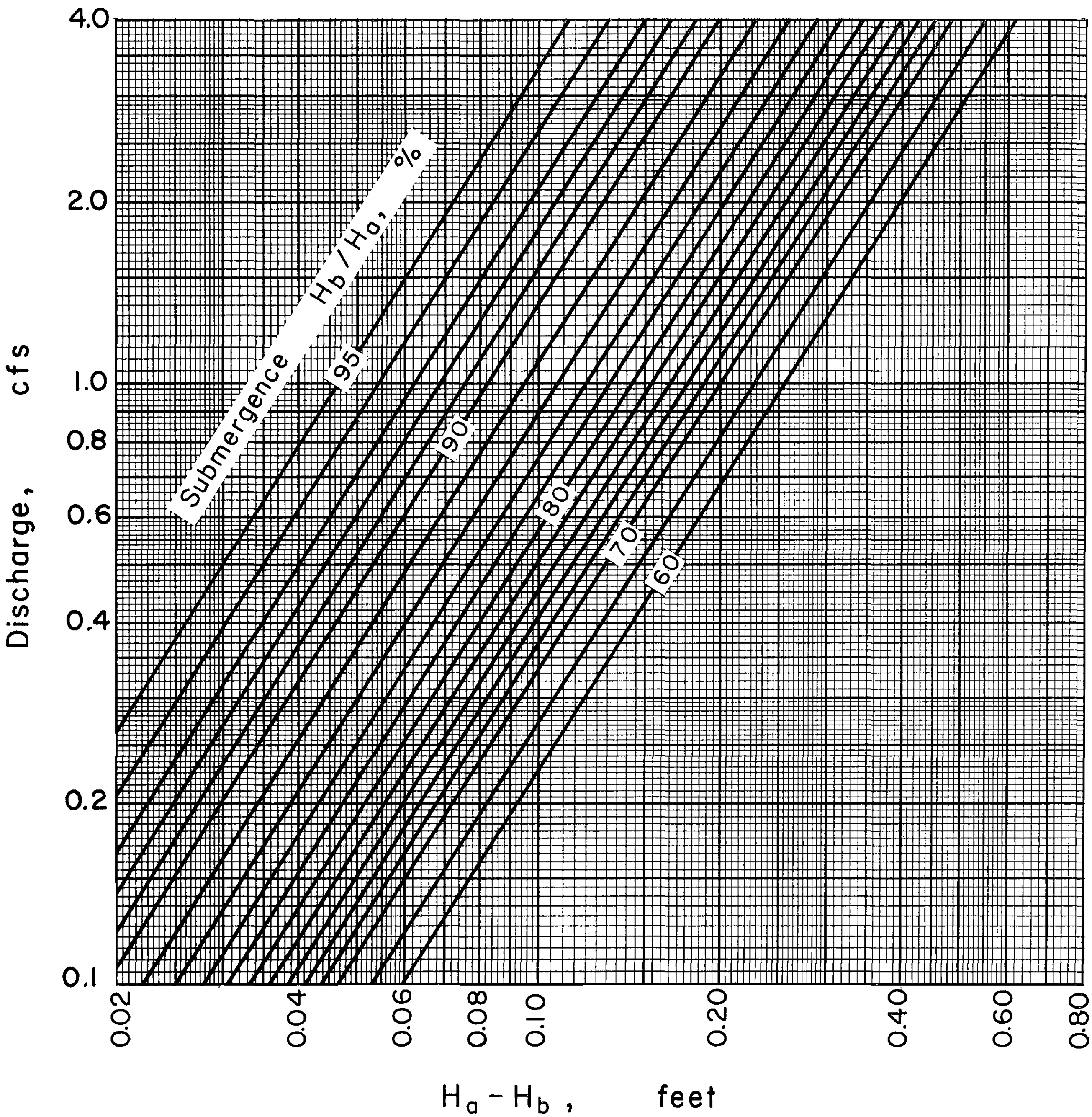

Figure 3. Submerged flow calibration curves for 6-inch Parshall flume.

The submerged flow discharge equation which fits the calibration curves shown in Figure 3 for the 6-inch Parshall flume is

$$Q = \frac{1.66\ (H_a - H_b)^{1.58}}{[-(\log H_b/H_a + 0.0044)]^{1.08}} \quad . \ . \ . \ . \ . \ . \ . \ 2$$

When Equations 1 and 2 are equated, the transition submergence solves to be 55 percent which checks with the 56 percent stated by Villemonte and Gunaji (1953).

The submerged calibration curves for the 6-inch Parshall flume as shown in Figure 3 are identical to those developed by Skogerboe, Hyatt, England, Johnson, and Griffin (1965) because the same data was used in the development of each.

ONE-FOOT PARSHALL FLUME

Experimental Facilities

A commerical fabricated steel 1-foot Parshall flume was used for the study. The 1-foot flume was placed in the 5-foot deep by 5-foot wide flume located in the Fluid Mechanics Laboratory at Utah State University. The flume was placed with the converging floor section level in all directions. Other necessary precautions were taken to insure the compatibility of the authors' results with those of Parshall (1953).

Three pumps were used which were capable of delivering a maximum flow rate of approximately eight cubic feet per second (cfs). The flow rate was regulated by varying the number of pumps on the line and by means of a valve located on the line as it entered the laboratory.

The flow passed through the flume and discharged into weighing tanks where the water was weighed over a given time period to obtain the flow rate. The water was then discharged from the weighing tanks into the sump, where it recirculated.

Depth measurements were made by the use of a point gage in stilling wells. The measurements were made to the nearest 0.001 foot.

A tailgate was placed downstream from the Parshall flume to regulate tailwater depth and thereby control and vary the degree of submergence for each flow rate.

Analysis of data

As was discussed in the section on the 6-inch Parshall flume, the first step in the analysis was the determination of the value of $H_a - H_b$ term. As previously mentioned, the value of the power of H_a in the free flow equation is to be the same as the value of the power of $H_a - H_b$ in the submerged flow equation. Hence, the free flow data was plotted with Q as the ordinate and H_a as the abscissa. The equation which resulted from this plot and corresponded with the equation listed by Parshall (1953) for a 1-foot flume is

$$Q = 4.0\, H_a^{1.52} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

Thus the value of the power of $H_a - H_b$ in the submerged flow equation is 1.52.

A three-dimensional log-log plot was prepared with Q plotted as the ordinate, $H_a - H_b$ as the abscissa, and H_b/H_a as the varying parameter (Figure 4). Figure 4 shows the lines of constant submergence to be at a slope of 1.52 and also gives further validity to the method of analyzing submerged flow developed at Utah State University. From Figure 4 a submerged flow calibration curve for a 1-foot Parshall flume was developed (Figure 5). Utilizing Figure 5, the submerged flow discharge equation obtained for the 1-foot flume is

$$Q = \frac{3.11\,(H_a - H_b)^{1.52}}{[-(\log H_b/H_a + 0.0044)]^{1.08}} \quad . \quad . \quad . \quad . \quad . \quad . \quad 4$$

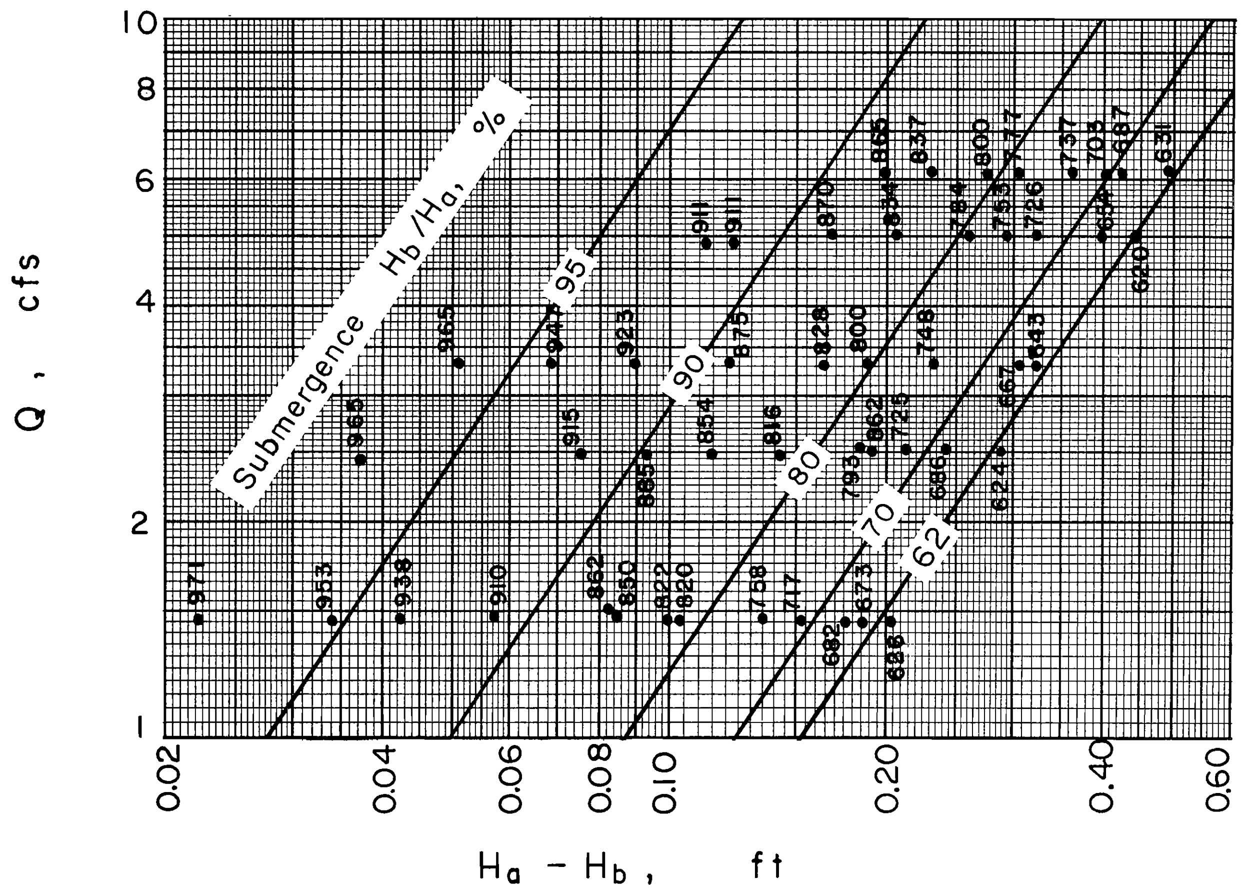

Figure 4. Plot of 1-foot Parshall flume submerged flow data.

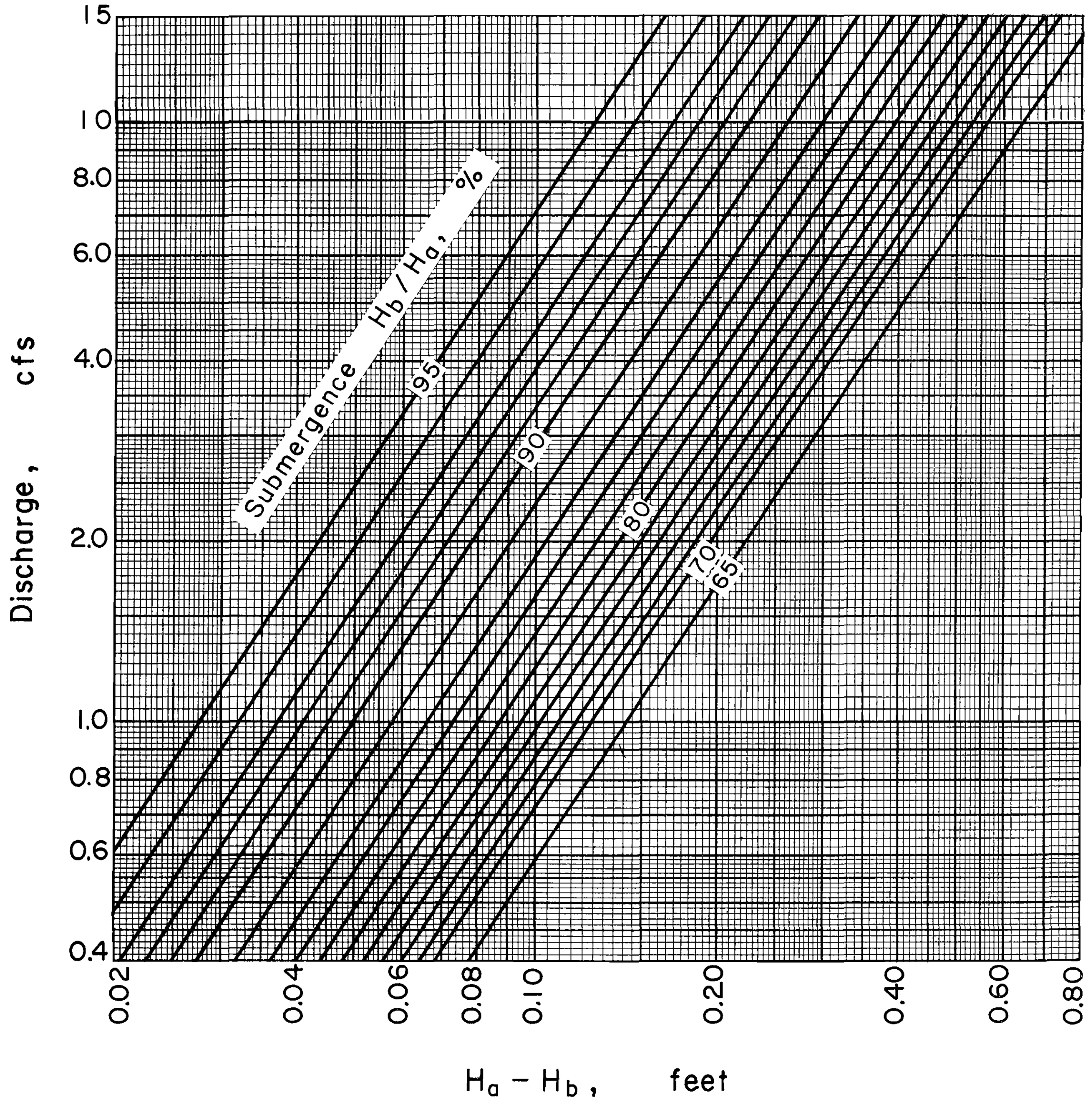

Figure 5. Submerged calibration curves for 1-foot Parshall flume.

When Equations 3 and 4 are equated, the transition submergence for the 1-foot Parshall flume solves to be 62 percent. The submerged calibration curve (Figure 5) developed from the data gathered by the authors at the Utah Water Research Laboratory is identical to the one previously developed by Skogerboe, Hyatt, England, Johnson, and Griffin (1965), and thus supplements that work.

FOUR-FOOT PARSHALL FLUME

Experimental Facilities

For the study, a commerical fabricated steel 4-foot Parshall flume was used. The 4-foot flume was placed in the 8-foot wide by 6-foot deep flume at the Utah Water Research Laboratory, and in such a manner that compatible results with those of Parshall (1941) would be insured.

The Utah Water Research Laboratory is located along side the Logan River. Upstream from the laboratory is a small storage reservoir which provides the water supply for laboratory studies. The flow rate from this reservoir was regulated by means of a valve located in the laboratory. Once the flow had passed through the 8-foot wide by 6-foot deep flume, it is discharged back into the Logan River. For the study, the flow rate was measured by a 3-foot Parshall flume placed on a stand in the laboratory 8-foot by 6-foot flume at sufficient height to always insure free flow operation. The upstream depth, H_a, of the 3-foot flume was measured in a stilling well by means of a point gage to the nearest 0.001 foot.

Depth measurements of the 4-foot Parshall flume were also made by the use of a point gage in stilling wells, and with the accuracy of 0.001 foot.

A hydraulically operated tailgate located at the end of the 8-foot by 6-foot flume in the laboratory was used to regulate the tailwater depth and thereby control and vary the degree of submergence for each flow rate.

Analysis of data

The free flow equation as given by Parshall (1953) and used for the analysis for the 4-foot Parshall flume is

$$Q = 16 H_a^{1.57} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 5$$

A three-dimensional log-log plot was prepared from the 4-foot Parshall flume data with Q plotted as the ordinate, $H_a - H_b$ as the abscissa, and H_b/H_a as the varying parameter (Figure 6). As shown in Figure 6, the lines of constant submergence fit the data best at a slope of 1. 57 (the same slope as the free flow equation). Figure 6 is also the submerged flow calibration curve for a 4-foot Parshall flume. The submerged flow discharge equation for the 4-foot flume as obtained from Figure 6 is

$$Q = \frac{11.10 \, (H_a - H_b)^{1.57}}{[-(\log H_b/H_a + 0.0044)]^{1.185}} \quad . \; . \; . \; . \; . \; . \; . \quad 6$$

Equation 6 and the submerged calibration curve (Figure 6) for the 4-foot Parshall flume are identical to the one developed previously by Skogerboe, Hyatt, England, Johnson, and Griffin (1965) resulting in further validity of the method of analyzing submerged flow as developed at Utah State University. When Equations 5 and 6 are equated the transition submergence for the 4-foot Parshall flume solves to be 70 percent.

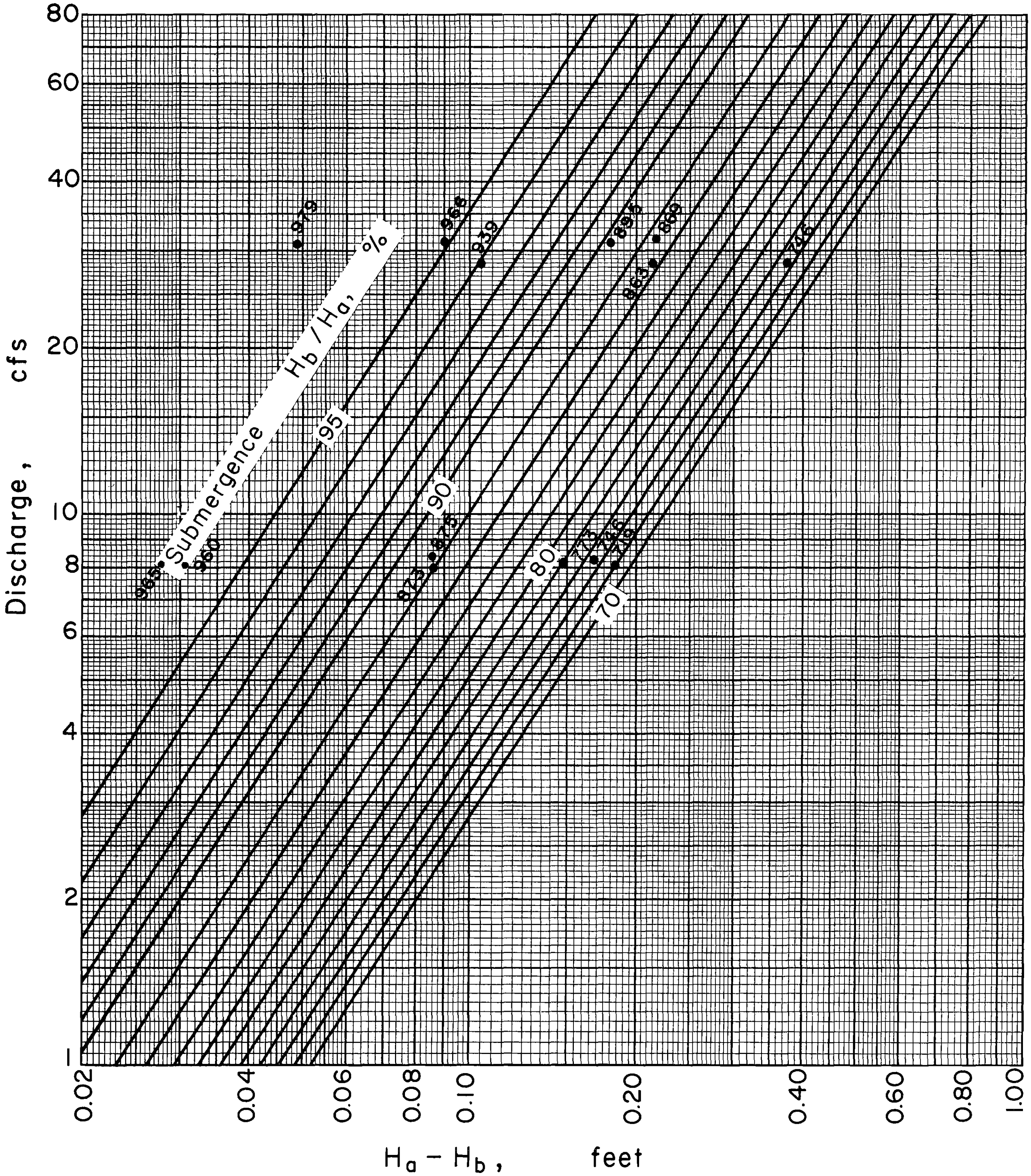

Figure 6. Submerged calibration curves for 4-foot Parshall flume with plotted flow data.

SIX-FOOT PARSHALL FLUME

Analysis of data

The data used for the analysis of the 6-foot Parshall flume was taken from a study on model-prototype conformity by Blaisdell (1944). The submerged flow data was interpolated from a plot where increase in head was plotted versus submergence for several discharge values.

A plot of the free flow data resulted in a free flow equation for the 6-foot Parshall flume of

$$Q = 24.6 H_a^{1.58} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 7$$

The equation given by Parshall (1953) for the 6-foot flume is

$$Q = 24.0 H_a^{1.595} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 8$$

The data for the 6-foot Parshall flume was plotted on a three-dimensional log-log plot with Q as the ordinate, $H_a - H_b$ as the abscissa, and H_b/H_a as the varying parameter (Figure 7). Figure 7 shows several lines of constant submergence which fit the data best when the slope is 1.58. A slope of 1.58 or 1.595 was indicated by the free flow equations--Equations 7 and 8--previously given. Since the slope of 1.58 works best for both the free flow condition and the submerged flow condition, it will be used in the analysis. Hence, the free flow equation to be used is Equation 7.

Figure 8 is the submerged flow calibration curve for a 6-foot Parshall flume as developed from the data of Blaisdell (1944). Figure 8 also gives further validity to the method of analyzing

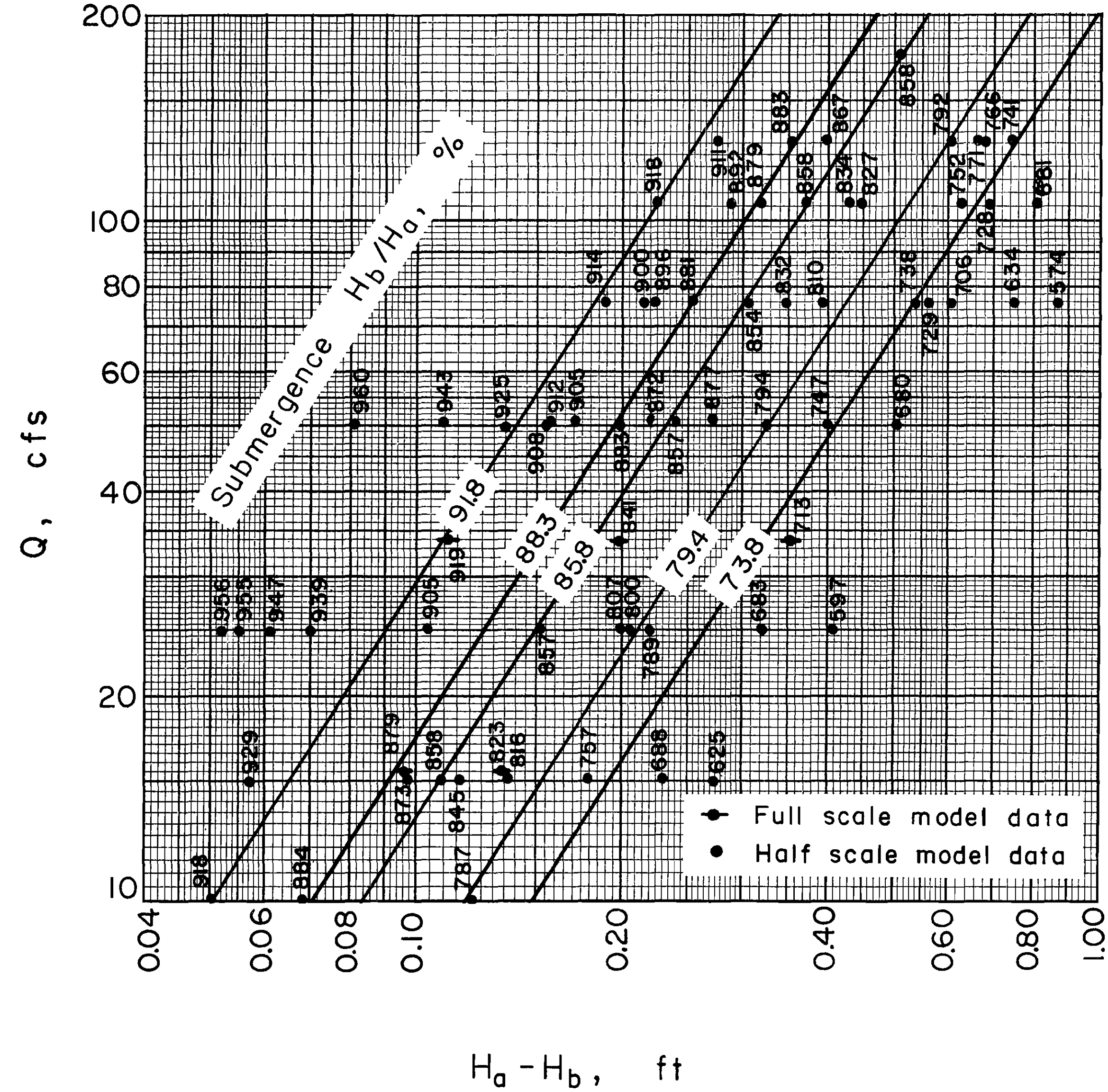

Figure 7. Plot of 6-foot Parshall flume submerged flow data.

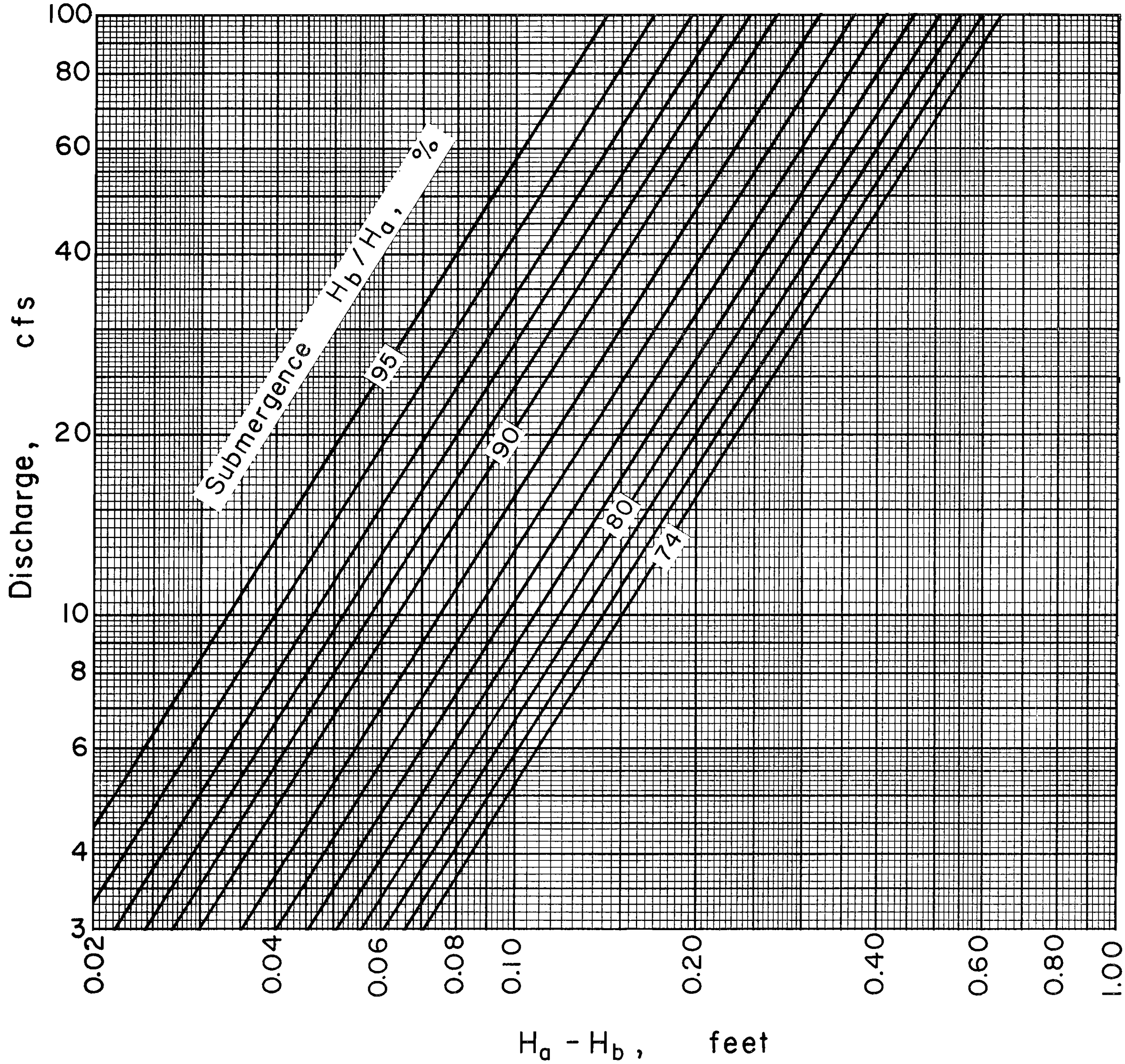

Figure 8. Submerged flow calibration curves for 6-foot Parshall flume.

submerged flow as previously described. Utilizing Figure 8, the submerged flow discharge equation for the 6-foot Parshall flume can be written as

$$Q = \frac{15.89\,(H_a - H_b)^{1.58}}{[-(\log H_b/H_a + 0.0044)]^{1.24}} \quad . \; . \; . \; . \; . \; . \; . \; . \; 9$$

The submerged flow calibration curve shown by Figure 8 is almost identical to the one developed previously by Skogerboe, Hyatt, England, Johnson, and Griffin (1965). The difference between the two calibration curves can best be illustrated by the difference in the discharge equations. The equation for the calibration curves previously developed is

$$Q = \frac{15.86\,(H_a - H_b)^{1.59}}{[-(\log H_b/H_a + 0.0044)]^{1.23}} \quad . \; . \; . \; . \; . \; . \; . \; . \; 10$$

as compared to Equation 9 developed from Figure 8. However, both the developed curves and Equations 9 and 10 give comparable answers.

The transition submergence of the 6-foot Parshall flume is 74 percent as obtained from equating Equations 7 and 9.

CONCLUSIONS

The 6-inch, 1-, 4-, and 6-foot Parshall flumes were selected as representative sizes for collecting submerged flow data. Data for the 1- and 4-foot flumes were collected by the authors at the Utah Water Research Laboratory. The data of Gunaji (1950) was used for the 6-inch flume, and the data of Blaisdell (1944) was used for the 6-foot flume.

The submerged flow data of the 6-inch, 1-, 4-, and 6-foot Parshall flumes were analyzed utilizing the method developed by Hyatt (1965). The calibration curves developed from the data of the 1-, 4-, and 6-foot flumes showed little, if any, variation when compared to the curves developed by Skogerboe, Hyatt, England, Johnson, and Griffin (1965). The transition points of 62, 70, and 74 percent, respectively, were identical with those previously obtained.

The submerged flow data for the 6-inch Parshall flume as reported by Gunaji was found to be compatible with the findings of Skogerboe, Hyatt, England, Johnson, and Griffin (1965) for lower submergence values (55 to 85 percent) but incompatible for higher submergence values (85 to 97 percent). Agreement on a transition submergence of 55 percent for the 6-inch flume was obtained, however.

The calibration curves developed for the 6-inch, 1-, 4-, and 6-foot Parshall flumes are shown in the report and all further supplement the work previously done.

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APPENDIX A

SUBMERGED FLOW DATA COLLECTED BY GUNAJI FOR 6-INCH PARSHALL FLUME

Table 2. Submerged flow data for 6-inch Parshall flume.

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
0.063	0.111	0.085	76.6	0.026
0.063	0.123	0.104	84.6	0.019
0.063	0.141	0.129	91.5	0.012
0.063	0.151	0.141	93.4	0.010
0.063	0.167	0.160	95.8	0.007
0.334	0.320	0.169	52.8	0.151
0.334	0.333	0.245	73.6	0.088
0.334	0.362	0.271	74.9	0.091
0.334	0.376	0.294	78.2	0.082
0.620	0.491	0.386	78.7	0.105
0.620	0.511	0.437	85.7	0.074
0.620	0.541	0.452	83.5	0.089
0.650	0.485	0.243	50.0	0.242
0.650	0.513	0.439	85.6	0.074
0.650	0.549	0.461	84.0	0.088
0.650	0.597	0.521	87.0	0.076
0.650	0.686	0.638	93.1	0.048
0.650	0.753	0.714	94.9	0.039
0.650	0.881	0.854	96.6	0.027
0.650	0.974	0.954	98.0	0.020
0.650	1.080	0.963	89.2	0.117
0.076	0.135	0.074	54.7	0.061
0.076	0.155	0.087	56.0	0.068
0.076	0.174	0.111	63.8	0.063
0.076	0.194	0.131	67.5	0.063
0.310	0.303	0.152	50.2	0.151
0.310	0.307	0.178	58.0	0.129
0.310	0.308	0.199	64.6	0.109
0.310	0.320	0.248	77.5	0.072
0.310	0.332	0.252	75.9	0.080
0.310	0.360	0.274	76.0	0.086
0.310	0.371	0.305	82.3	0.066
0.310	0.397	0.339	85.5	0.058
0.310	0.440	0.394	89.5	0.046
0.310	0.478	0.436	91.5	0.042
0.310	0.516	0.478	92.6	0.038
0.310	0.571	0.537	94.0	0.034
0.310	0.629	0.600	95.5	0.029
0.310	0.673	0.643	95.7	0.030
0.310	0.733	0.705	96.5	0.028

Table 2. (Continued)

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
0.693	0.513	0.340	66.3	0.173
0.693	0.517	0.362	70.0	0.155
0.693	0.522	0.389	74.3	0.133
0.690	0.528	0.414	78.5	0.114
0.690	0.535	0.439	82.0	0.096
0.690	0.541	0.452	83.6	0.089
0.687	0.549	0.472	86.0	0.077
0.687	0.578	0.482	83.4	0.096
0.682	0.594	0.493	83.2	0.101
0.682	0.605	0.516	85.5	0.089
0.678	0.625	0.544	87.0	0.081
0.678	0.641	0.567	88.5	0.074
0.676	0.689	0.626	91.0	0.063
0.676	0.743	0.691	93.2	0.052
0.675	0.766	0.720	94.0	0.046
0.672	0.801	0.760	95.0	0.041
0.672	0.860	0.825	96.0	0.035
0.671	0.954	0.926	97.4	0.028
1.580	0.858	0.491	57.4	0.367
1.580	0.882	0.622	70.5	0.260
1.580	0.911	0.708	77.6	0.203
1.580	0.961	0.816	84.9	0.145
1.550	0.995	0.877	88.2	0.118
1.550	1.019	0.911	89.6	0.108
1.550	1.044	0.948	90.6	0.096
1.550	1.095	0.983	89.8	0.112
1.550	1.118	1.005	90.0	0.113
1.550	1.141	1.033	90.5	0.108
1.520	1.193	1.094	91.8	0.099
1.520	1.251	1.169	93.4	0.082
1.520	1.306	1.229	94.0	0.077
1.520	1.354	1.283	94.7	0.071
1.500	1.426	1.368	96.6	0.058
1.500	1.510	1.459	96.7	0.051
0.220	0.335	0.206	61.5	0.129
0.220	0.400	0.381	95.4	0.019
0.220	0.450	0.435	96.8	0.015
0.220	0.490	0.478	97.5	0.012
2.068	1.019	0.596	58.6	0.423
2.068	1.043	0.723	69.3	0.320

Table 2. (Continued)

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
2.060	1.086	0.855	78.7	0.231
2.060	1.161	0.993	85.5	0.168
2.060	1.183	1.040	88.0	0.143
2.060	1.220	1.092	89.8	0.128
2.060	1.264	1.155	91.5	0.109
2.050	1.302	1.200	92.2	0.102
2.050	1.340	1.247	93.0	0.093
2.050	1.390	1.273	91.7	0.117
2.050	1.419	1.307	92.2	0.112
2.050	1.461	1.359	93.0	0.102
2.050	1.520	1.423	93.8	0.097
2.040	1.580	1.496	94.6	0.084
2.040	1.652	1.575	95.3	0.077
2.040	1.691	1.622	96.0	0.069
2.040	1.731	1.664	97.4	0.067
2.020	1.750	1.686	96.5	0.064
2.020	1.771	1.716	97.0	0.055

APPENDIX B

DATA COLLECTED BY UTAH WATER RESEARCH LABORATORY FOR 1-FOOT PARSHALL FLUME

Table 3.

Measurements and computation of parameters for 1-foot Parshall flume.

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
1.430	0.536		FREE	FLOW
1.452	0.540	0.306	56.6	0.234
1.455	0.541	0.364	67.3	0.177
1.462	0.547	0.412	76.1	0.135
1.462	0.555	0.456	82.2	0.099
1.460	0.567	0.482	85.0	0.085
1.455	0.592	0.506	85.6	0.086
1.460	0.631	0.574	91.0	0.057
1.455	0.680	0.638	93.8	0.042
1.440	0.724	0.690	95.3	0.034
1.440	0.776	0.754	97.1	0.022
1.465	0.583	0.502	86.2	0.081
1.455	0.567	0.465	82.0	0.102
1.466	0.554	0.420	75.8	0.134
1.430	0.535	0.365	68.2	0.170
1.425	0.536	0.384	71.7	0.152
1.427	0.529	0.206	39.0	0.323
1.440	1.114	1.102	98.9	0.012
1.442	0.536	0.331	62.0	0.203
1.429	0.532	0.316	59.4	0.216
1.435	0.534	0.351	65.7	0.183
2.530	0.755		FREE	FLOW
2.520	0.762	0.465	61.0	0.297
2.520	0.761	0.428	56.0	0.333
2.520	0.759	0.406	53.6	0.353
2.525	0.763	0.477	62.5	0.286
2.525	0.768	0.527	68.6	0.241
2.520	0.770	0.558	72.5	0.212
2.525	0.779	0.617	79.3	0.182
2.461	0.795	0.703	88.5	0.092
2.461	0.795	0.685	86.2	0.110
2.461	0.778	0.665	85.4	0.113
2.461	0.770	0.628	81.6	0.142
2.461	0.882	0.807	91.5	0.075
2.435	1.110	1.073	96.5	0.037

Table 3. (Continued)

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
2.450	1.312	1.294	98.8	0.018
6.020	1.310		FREE	FLOW
6.090	1.362	1.059	77.7	0.303
6.090	1.382	1.109	80.0	0.273
6.090	1.411	1.182	83.7	0.229
6.090	1.463	1.267	86.5	0.196
6.090	1.352	0.951	70.3	0.401
6.130	1.351	0.929	68.7	0.422
6.130	1.345	0.857	63.7	0.488
6.160	1.347	0.824	61.0	0.523
6.290	1.355	0.789	58.2	0.566
6.410	1.356		FREE	FLOW
4.980	1.153		FREE	FLOW
4.980	1.151		FREE	FLOW
5.200	1.180	0.583	49.4	0.597
4.940	1.160	0.583	50.3	0.577
4.980	1.160	0.614	53.0	0.546
4.980	1.169	0.775	65.4	0.394
4.980	1.160	0.719	62.0	0.441
4.980	1.180	0.888	75.3	0.292
4.980	1.181	0.859	72.6	0.322
4.980	1.198	0.939	78.4	0.259
4.980	1.222	1.018	83.4	0.204
4.980	1.280	1.115	87.0	0.165
4.690	1.258	1.146	91.1	0.112
4.690	1.373	1.251	91.1	0.122
3.350	0.897		FREE	FLOW
3.340	0.896		FREE	FLOW
3.320	0.899	0.516	57.4	0.373
3.310	0.902	0.536	59.4	0.366
3.310	0.905	0.581	64.3	0.324
3.320	0.907	0.605	66.7	0.302
3.310	0.914	0.684	74.8	0.230
3.320	0.932	0.745	80.0	0.187
3.320	0.941	0.780	82.8	0.161

Table 3. (Continued)

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
3.310	0.962	0.842	87.5	0.120
3.300	1.029	0.911	88.6	0.118
3.300	1.138	1.049	92.3	0.089
3.300	1.304	1.236	94.7	0.068
3.300	1.453	1.402	96.5	0.051

APPENDIX C

DATA COLLECTED BY
UTAH WATER RESEARCH LABORATORY
FOR 4-FOOT PARSHALL FLUME

Table 4.

Measurements and computation of parameters for 4-foot Parshall flume.

Q	H_a	H_b	$H_a - H_b$	H_b/H_a
28.60	1.466	1.093	0.373	0.746
28.60	1.559	1.345	0.214	0.863
28.40	1.732	1.628	0.104	0.939
30.80	2.311	2.262	0.049	0.979
30.80	1.650	1.433	0.217	0.869
30.50	1.688	1.509	0.179	0.895
30.50	1.937	1.852	0.085	0.966
8.11	0.657	0.490	0.167	0.746
8.01	0.649	0.502	0.147	0.773
8.01	0.654	0.470	0.184	0.719
8.01	0.672	0.586	0.086	0.873
8.01	0.763	0.732	0.031	0.960
8.01	0.794	0.766	0.028	0.965
8.20	0.691	0.605	0.086	0.875

APPENDIX D

SUBMERGED FLOW
DATA COLLECTED BY BLAISDELL
FOR 6-FOOT PARSHALL FLUME

Table 5. Full scale model data for 6-foot Parshall flume.

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
33.700	1.2250	0.8730	71.3	0.3520
33.700	1.2430	1.0450	84.1	0.1980
33.700	1.3790	1.2670	91.9	0.1120
15.500	0.7580	0.6240	82.3	0.1340
15.500	0.7880	0.6920	87.9	0.0960
15.500	0.8490	0.7920	93.3	0.0570
15.500	0.8920	0.8570	96.1	0.0350
4.060	0.1162	0.0588	50.6	0.0574
4.060	0.1169	0.0925	79.1	0.0244
4.060	0.1183	0.1004	84.9	0.0179
4.060	0.1196	0.1042	87.1	0.0154
4.060	0.1253	0.1152	91.9	0.0101
4.060	0.1309	0.1237	94.4	0.0072
4.060	0.1455	0.1423	97.8	0.0022
1.060	0.1650	0.1553	94.1	0.0100
1.060	0.1410	0.1230	87.3	0.0180
1.060	0.1380	0.1140	82.7	0.0240
0.821	0.1155	0.0681	59.0	0.0474
0.821	0.1178	0.0997	84.6	0.0180
0.821	0.1221	0.1095	89.7	0.0126
0.821	0.1381	0.1302	94.3	0.0079
0.493	0.0843	0.0627	74.4	0.0216
0.493	0.0886	0.0798	90.1	0.0088
0.493	0.0975	0.0917	94,0	0.0058
0.493	0.1041	0.0997	95.8	0.0043

Table 6. Half scale model data for 6-foot Parshall flume.

Q	H_a	H_b	H_b/H_a, %	$H_a - H_b$
131.00	2.875	2.130	74.10	0.745
131.00	2.884	2.209	76.60	0.675
131.00	2.892	2.230	77.10	0.662
131.00	2.904	2.300	79.20	0.604
131.00	2.967	2.572	86.70	0.395
131.00	3.030	2.676	88.30	0.354
131.00	3.105	2.829	91.10	0.276
49.80	1.802	1.667	92.50	0.135
49.80	1.748	1.594	91.20	0.154
49.80	1.695	1.497	88.30	0.198
49.80	1.663	1.443	86.80	0.220
49.80	1.614	1.420	88.00	0.194
49.80	1.600	1.374	85.90	0.226
49.80	1.581	1.255	79.40	0.326
49.80	1.573	1.175	74.70	0.398
49.80	1.567	1.066	68.00	0.501
25.00	1.009	0.602	59.70	0.407
25.00	1.013	0.692	68.30	0.321
25.00	1.020	0.810	79.40	0.210
25.00	1.025	0.820	80.00	0.205
25.00	1.035	0.835	80.70	0.200
25.00	1.045	0.825	78.90	0.220
25.00	1.056	0.904	85.65	0.152
25.00	1.098	0.994	90.50	0.104
25.00	1.145	1.075	93.90	0.070
25.00	1.159	1.098	94.70	0.061
25.00	1.190	1.135	95.40	0.055
25.00	1.193	1.141	95.60	0.052
25.00	1.207	1.153	95.50	0.054
15.00	0.803	0.746	92.90	0.057
15.00	0.779	0.670	89.80	0.109
15.00	0.765	0.668	87.30	0.097
15.00	0.747	0.631	84.50	0.116
15.00	0.740	0.604	81.60	0.136
15.00	0.733	0.555	75.70	0.178
15.00	0.730	0.502	68.80	0.228
15.00	0.729	0.456	62.50	0.273
9.86	0.629	0.591	94.00	0.038
9.86	0.616	0.573	93.10	0.043
9.86	0.607	0.557	91.80	0.050