PAP-535

PAP-535

Study of Submerged Flow in Parshall Flumes

H. W. Peck
September 15, 1988

PAP-535

D-3751
(PAP file)
PAP-535

UNITED STATES GOVERNMENT

Memorandum

Memorandum — Denver, Colorado

TO : Chairman, OCCS Committee — DATE: September 15, 1988

THROUGH: Chief, Hydraulics Branch

FROM : Head, Hydraulic Equipment Section

SUBJECT : Study of Submerged Flow in Parshall Flumes

The first objective of the subject study was completed in May. A memorandum report dated April 26, 1988, was sent to you that summarized the results of the work that was sponsored by the Open and Closed Conduit System (OCCS) Committee.

The enclosed paper summarizes the results to date and details recommendations for further study. It is requested that OCCS provide funding for Phase I. The estimated cost of Phase I is $10,000.

Due to a heavy workload the study cannot be continued until the third quarter of FY89.

Clifford A. Pugh

Enclosure

cc: D-3700
(w/encl)
D-3750
(w/encl)
D-3751 (PAP file)
(w/encl)
D-3752
(w/encl)
D-3752 (Peck)
(w/encl)
D-3120
(w/encl)
D-5200
(w/encl)

WBR:HPeck:flh:9-15-88:236-6146
(Document 008)

INTRODUCTION

Accurate open channel flow measurement is becoming more essential as increased emphasis is placed on efficient management of our water resources. One area where significant errors in flow measurement are known to occur is in the submerged flow region of Parshall flumes. For this reason the Bureau of Reclamation in the Water Measurement Manual states "the desirability of setting the flume sufficiently high to eliminate insofar as possible the need for the downstream H_b gage readings cannot be overemphasized." However the statement is also made that "to conserve head and embankment costs, designers sometimes set a maximum allowable percent submergence for the maximum design discharge, for example, 95 percent and 20 second-feet respectively." Parshall flumes originally designed to operate under free flow conditions may ultimately operate under submerged conditions due to factors such as construction of new check structures, deposits of sediment, deterioration of canal banks, and growths of weeds, tree roots, moss, and other biological organisms which tend to raise the downstream water level. More accurate flow measurement in the submerged region of Parshall flumes will increase measurement accuracy of flumes already in use and will be an aid in the economical design of flumes not yet built. The Water Measurement Manual also states that "excessive head may result from [setting the flume sufficiently high to eliminate...the need for the downstream H_b gage readings], and the higher exit velocities may make it necessary to provide scour protection at the flume exit." More accurate flow measurement in the submerged region may , in many cases, provide sufficient measurement accuracy to allow a lower flume setting and thereby eliminate the need for scour protection.

Data were collected in the hydraulic laboratory's 1-foot Parshall flume at constant upstream heads (H_a) of 0.6, 1.0, 1.5, and 2.0 feet. Data at submergence of 60 percent or less were used to develop a free flow equation. There is little difference between this free flow equation and Parshall's free flow equation for 1-foot flumes. Two equations that correct for submergence effects were developed as an alternative to Parshall's submergence correction. One equation corrects for submergence effects at flows to the right of a discontinuity; the other corrects for submergence effects at flows to the left of a discontinuity. Both of these equations differ significantly from Parshall's submergence correction equation for 1-foot flumes.

Shown plotted on figures 1 through 4 at the indicated values of H_a are the data collected for this study, the curves representing the equation developed in this study (USBR), and the curves representing Parshall's equation.

THE NEED FOR FURTHER STUDY

There is a significant difference between our data and Parshall's equation at each H_a (figures 1-4). The aspect ratio is defined as Ha/W, where W is the flume throat width. For the 1-foot flume the discontinuity in the discharge/submergence relationship is greatest at low aspect ratios (Ha=0.6 and 1.0). The maximum depth in 2-8 foot flumes is the same as in 1 foot flumes, 2.5 feet, therefore as the flume size is increased the aspect ratio will decrease. It is likely the same discontinuity occurs in larger flumes because the discontinuity is greatest in 1-foot flumes at low aspect ratios.

For a constant value of submergence and H_a the submergence correction portion of Parshall's equation for 1-8 foot flumes varies between flume size by the flume throat width raised to the 0.815 power ($W^{0.815}$). The error in Parshall's submergence correction equation for 1-foot flumes would probably have biased the calculation of this relationship even if the discontinuity does not occur in larger flumes.

Until a relationship between the error in Parshall's submergence correction equation and a non-dimensional parameter is defined it would be expected that the discontinuity discovered in our study and the associated error in Parshall's equation would affect flumes of all sizes.

One through eight foot flumes are not related to each other according to Froude scaling. Figure 5 indicates the percent difference between the discharge calculated with Parshall's free flow equation for a 1-foot flume and the discharge calculated with his free flow equation for an 8-foot flume scaled down to a 1-foot throat width for various values of H_a. As indicated in figure 5, Parshall's free flow equation for a 1-foot flume is not related to his free flow equation for an 8-foot flume according to Froude scaling. This difference is due to different relative geometric boundaries as the flume throat width is varied (geometric similarity is not maintained). As a result a minimum of three flumes in the 1-8 foot size range are recommended to be studied to develop equations for all the intermediate sizes. Future results may indicate that a study should be performed on every size flume.

RECOMMENDATIONS FOR FURTHER STUDY

Figure 6 shows additional data recently collected on the 1-foot flume at a constant discharge of 2.5 ft^3/s. The PID controller was used to maintain this discharge. Tailboards were added and removed to vary the submergence and upstream head. The change in upstream head was not great enough to significantly alter the discharge at the pump, therefore the only factor effecting the settling time required to reach steady state conditions was the change in downstream resistance. In contrast, when H_a was held constant, both the change in downstream resistance and the time required for the controller to adjust the discharge to maintain a constant H_a effected the settling time required to reach steady state conditions. The data shown on figure 6 were collected in 6 hours. The same amount of data collected at a constant H_a would require approximately 16 hours to collect. The information contained in the data shown on figure 6 is comparable to the information contained in the same number of data collected at a constant H_a. Therefore, future data will be collected while keeping discharge constant as opposed to holding the upstream head constant.

The average discharge of all the data plotted on figure 6 is 2.50 ft^3/s. The standard deviation of the discharge is 0.003 ft^3/s (0.13 %). The difference between the maximum discharge and the minimum discharge is 0.44 percent. It was noted that the controller slowly drifted such that the discharge gradually decreased over time. The set point of the controller was increased once to adjust for the drift in discharge. In the future, closer control of the drift in discharge should reduce the standard deviation and the percent difference between the maximum and minimum discharge to even smaller values than indicated above.

The following recommendations are for 1-8 foot flumes. The results of the second phase of the study may indicate that Parshall's submergence correction equation is sufficiently accurate for flumes above a certain size. If so the remainder of the study recommendations may change significantly.

Phase I

In Phase I data will be collected at constant discharges. This data will be used to redevelop the discharge/submergence equations for the 1-foot flume. It is expected that a complete H_a/submergence curve, including the free flow zone, can be developed in 1 working day. Initially H_a/submergence data at 4 different discharges will be used to develop the discharge/submergence equations. These equations will be compared to the ones previously developed using data collected at 4 different H_a's. Data will then be obtained at intermediate discharges. A sensitivity analysis will be performed to determine the effect when the discharge/submergence equations are developed from a larger data base. This process will continue until the addition of new data no longer significantly alters the discharge/submergence equations.

Of the different types of upstream wing walls that are used in Parshall flumes, the walls presently in place in the 1-foot flume are among the least conducive to smooth flow conditions at the flume entrance. These wing walls will be modified to provide smoother entrance conditions. Additional data will then be collected to determine if this has an effect on the discharge/submergence relationship.

One-foot Parshall flumes are commonly constructed of steel, therefore the surface roughness of the hydraulic laboratory's flume closely matches that of many 1-foot flumes. However, 1-foot flumes are also constructed of other materials such as concrete. Data will be collected with the flow surface of the flume roughened to determine friction effects on the discharge/submergence relationship.

Phase II

In Phase II a 3-foot throat width scale model of a 7-foot flume (3:7 scale) will be installed in place of the current 1-foot width flume. This relatively large model will minimize scale effects. The maximum prototype discharge of 121.4 $ft.^3/s$ will be simulated by 14.6 $ft.^3/s$ model discharge. The sides of the model flume will be constructed higher than necessary to model a 7-foot flume so that parameters can be studied beyond the range that would occur in the normal operation range of the prototype. This will allow us to follow the discontinuity even if it occurs outside of the normal operation zone.

Data will be collected on the 3-foot model at the number of constant discharges required to accurately define the discharge/submergence relationship of the 7-foot prototype. The number of discharges at which data must be collected will be obtained from the sensitivity analysis performed in Phase I.

Results from Phase I will indicate if the effects of entrance conditions and surface roughness need to be studied in Phase II.

Phase III

In Phase III a flume of size to be determined by the results of Phase II will be studied. If previous results indicate the need, the model used in Phase II will be modified to a 3:5 scale model of a 5-foot flume. At a 3:5 scale the maximum discharge of 85.6 $ft.^3/s$ for a 5-foot flume is 23.9 $ft.^3/s$ model discharge. If a 5-foot flume is studied it is probable that a Phase IV will be required in which a 3-foot flume will be studied.

If the results from Phase II indicate that Parshall's equations are sufficiently accurate for larger flumes, a 3-foot flume will be studied using a 2:3 scale model. At a 2:3 scale the maximum discharge of 50.4 $ft.^3/s$ for a 3-foot flume is 18.3 $ft.^3/s$ model discharge.

TIME AND COST ESTIMATES

For Phase I it was originally proposed to collect data at additional H_a's to determine the effect when the discharge/submergence equations are developed from a larger data base and to investigate the effect of flume entrance conditions and surface roughness on the discharge/submergence relationship. The estimated cost for Phase I in the original proposal was approximately the same as in the current proposal. Therefore collection of data at constant discharge rather than at constant H_a will not reduce study costs for Phase I. However, estimates of study costs for subsequent Phases are considerably reduced by the new data collection methodology.

No time and cost estimates were prepared for Phase III as they will vary widely depending on the results of Phase II.

		Time (Staff Days)	Cost ($)
Phase I:	Install instrumentation	4	960
	Write computer program	2	480
	Modify flume	5	1,200

Collect data	20	4,800
Analyze data	10	2,400
Total	41	9,840
Phase II: Replace flume	25	6,000
Flume material		1,000
Collect data	15	3,600
Analyze data	15	3,600
Write memo	15	3,600
Total	70	17,800

CONCLUSION

Phase I-IV will complete the empirical study of 1-8 foot flumes. Either during the course of the empirical study or after the empirical study is completed a theoretical analysis should be performed in an attempt to explain the cause of the discontinuity. The final results of this study will indicate whether or not additional study on 10-50 foot Parshall flumes is needed.

In Phase II the existing model will be utilized, the major modification will be replacing the 1-foot flume with a nonstandard 3-foot flume. The 3-foot flume will be a scale model (3:7 scale) of a 7-foot flume.

Significant progress is anticipated for each phase toward redefining submerged flow parameters in Parshall flumes.

Figure 1 - Ha=0.6 Ft.

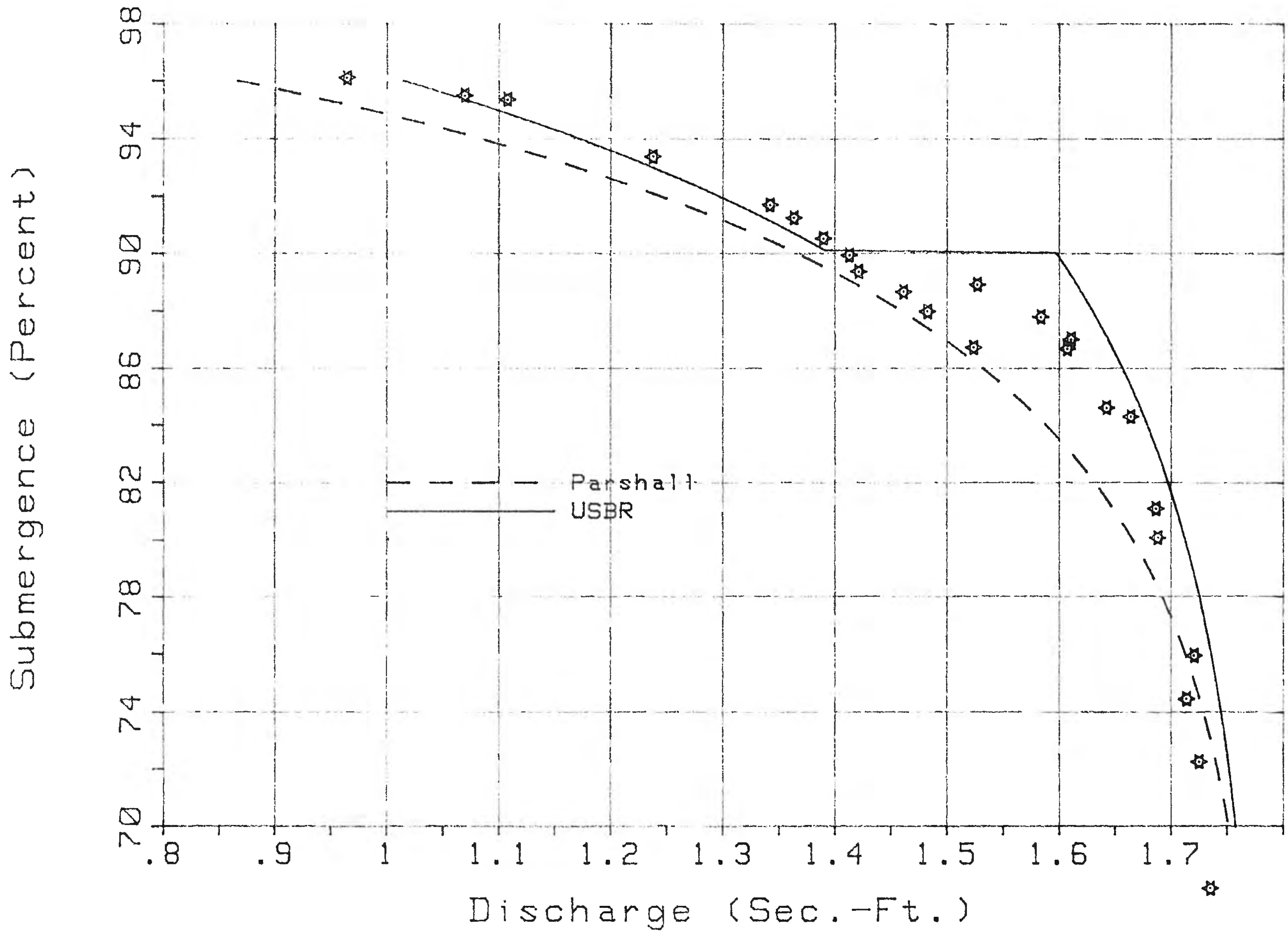

Figure 2 - Ha=1.0 Ft.

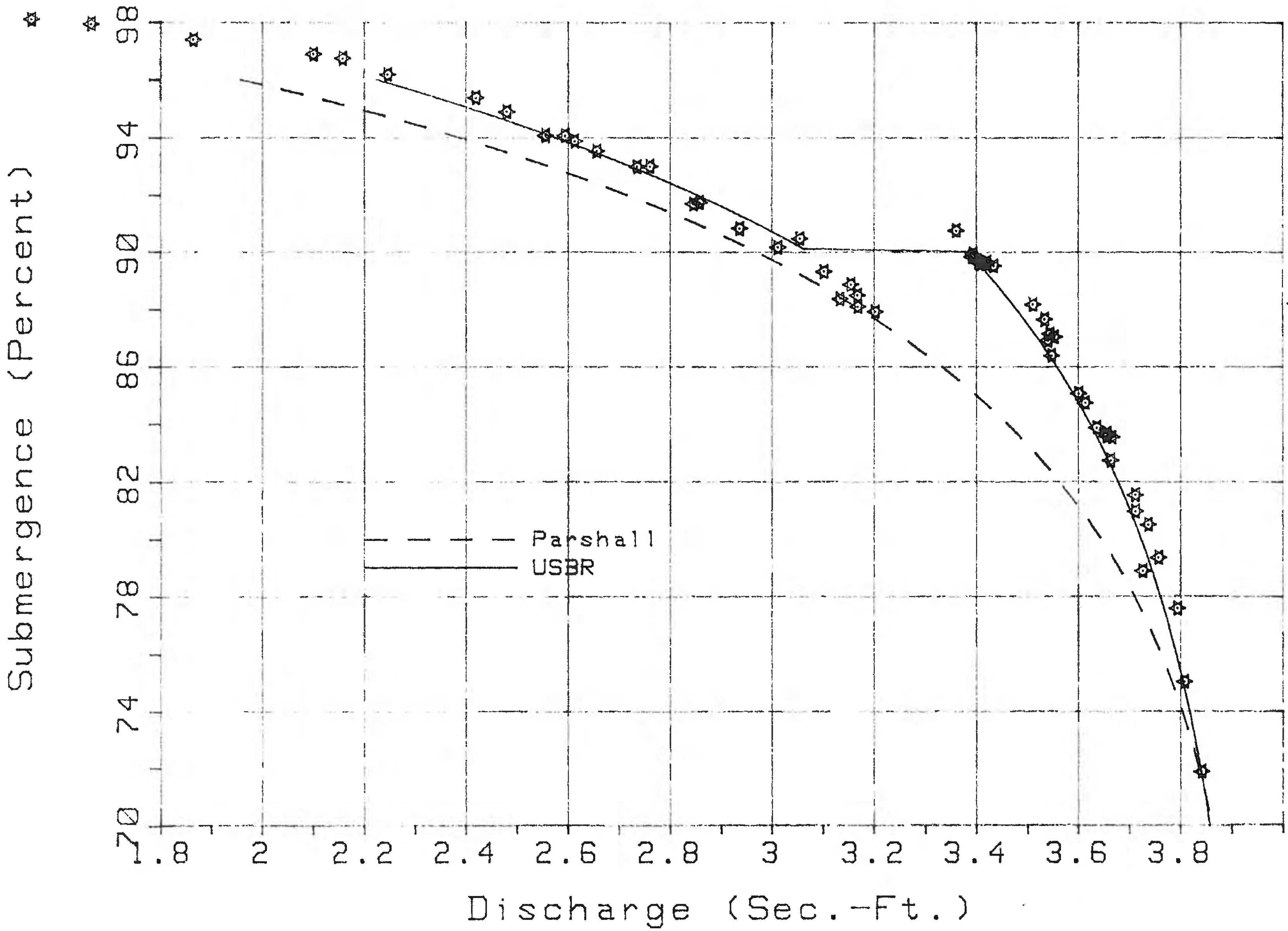

Figure 3 - Ha=1.5 Ft.

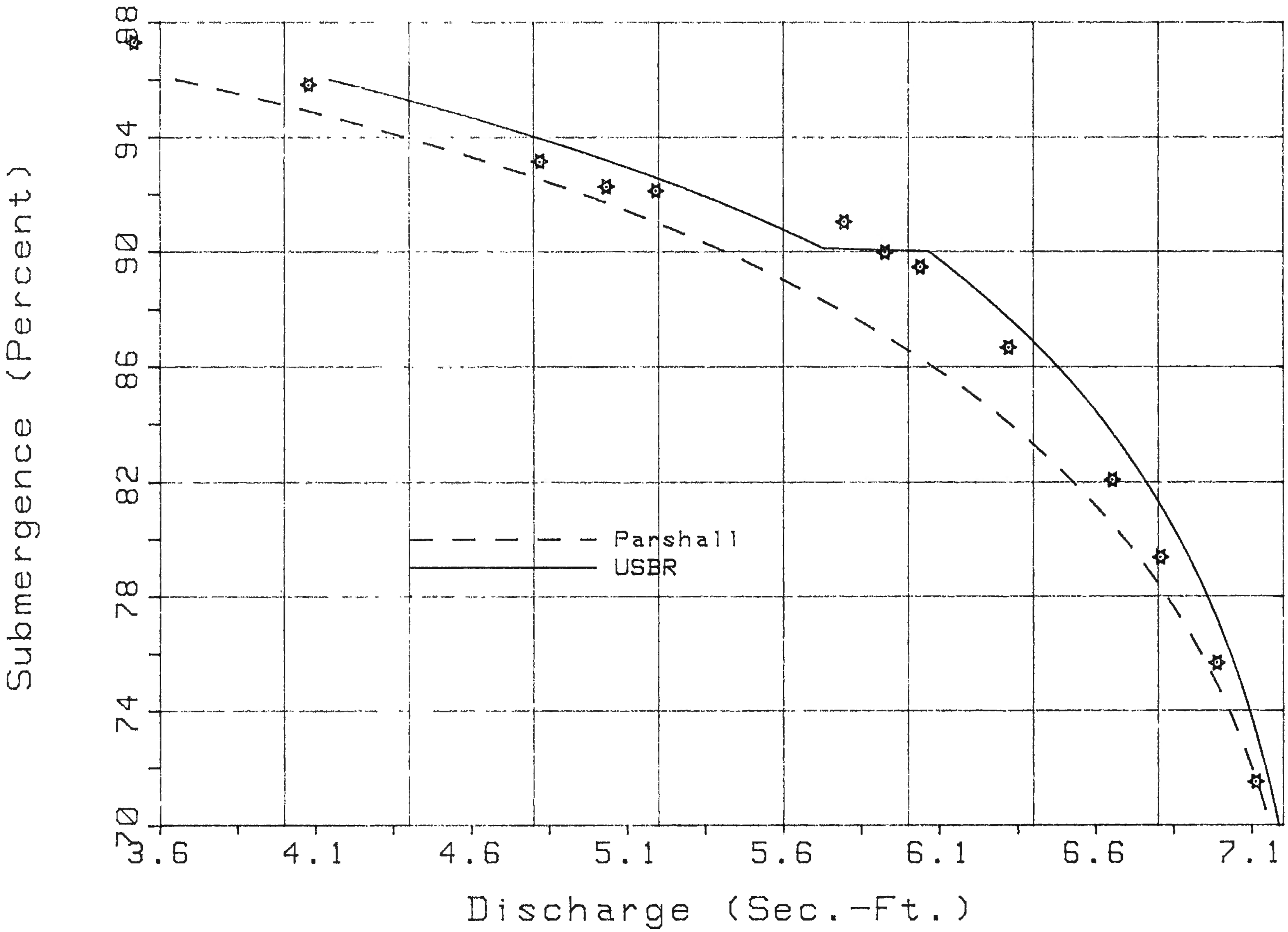

Figure 4 - Ha=2.0 Ft.

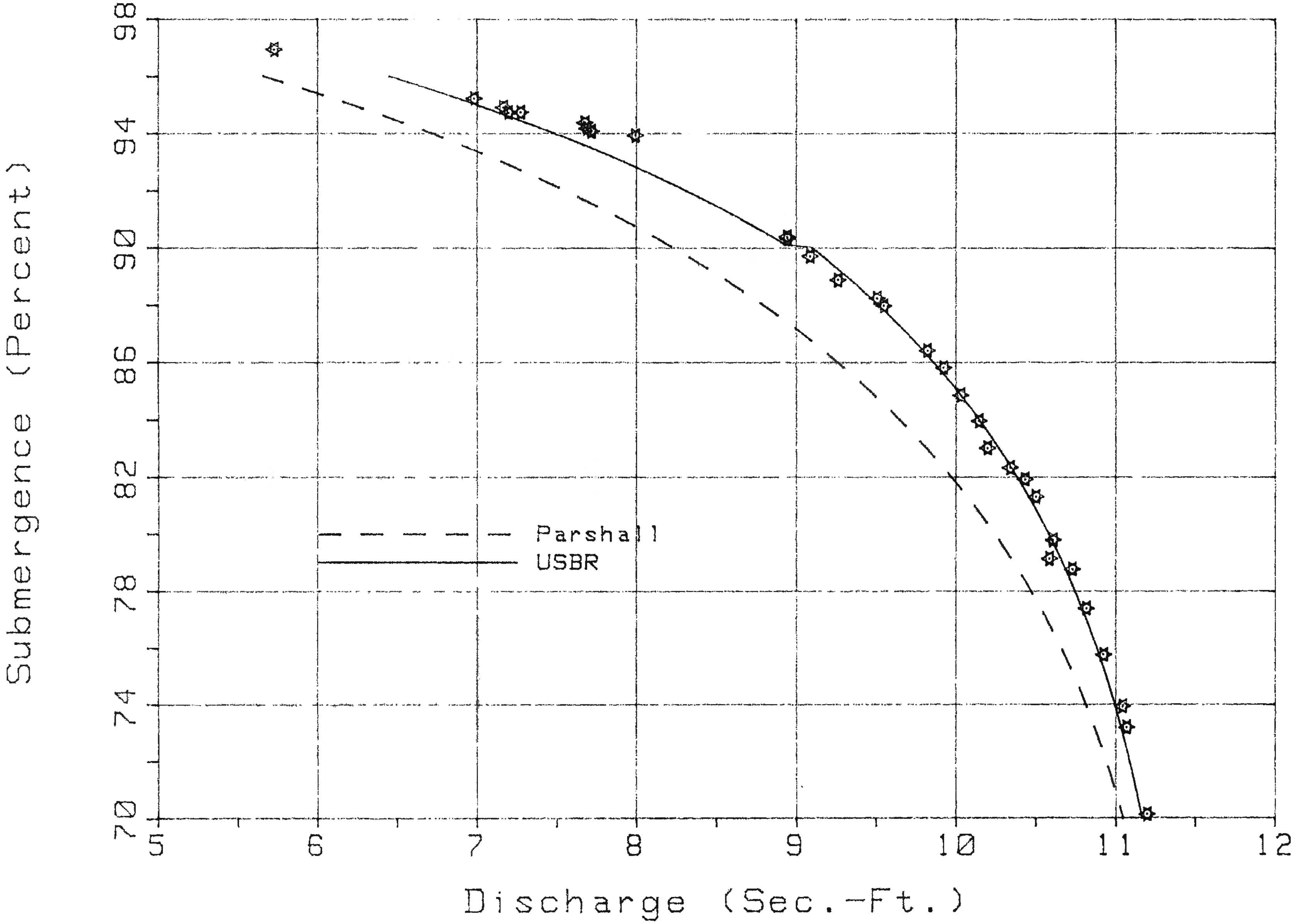

FIGURE 5

% DIFF. BETWEEN PARSHALL'S EQ'N FOR A 1-FT. & EQ'N FOR 8-FT SCALED DOWN TO 1-FT.

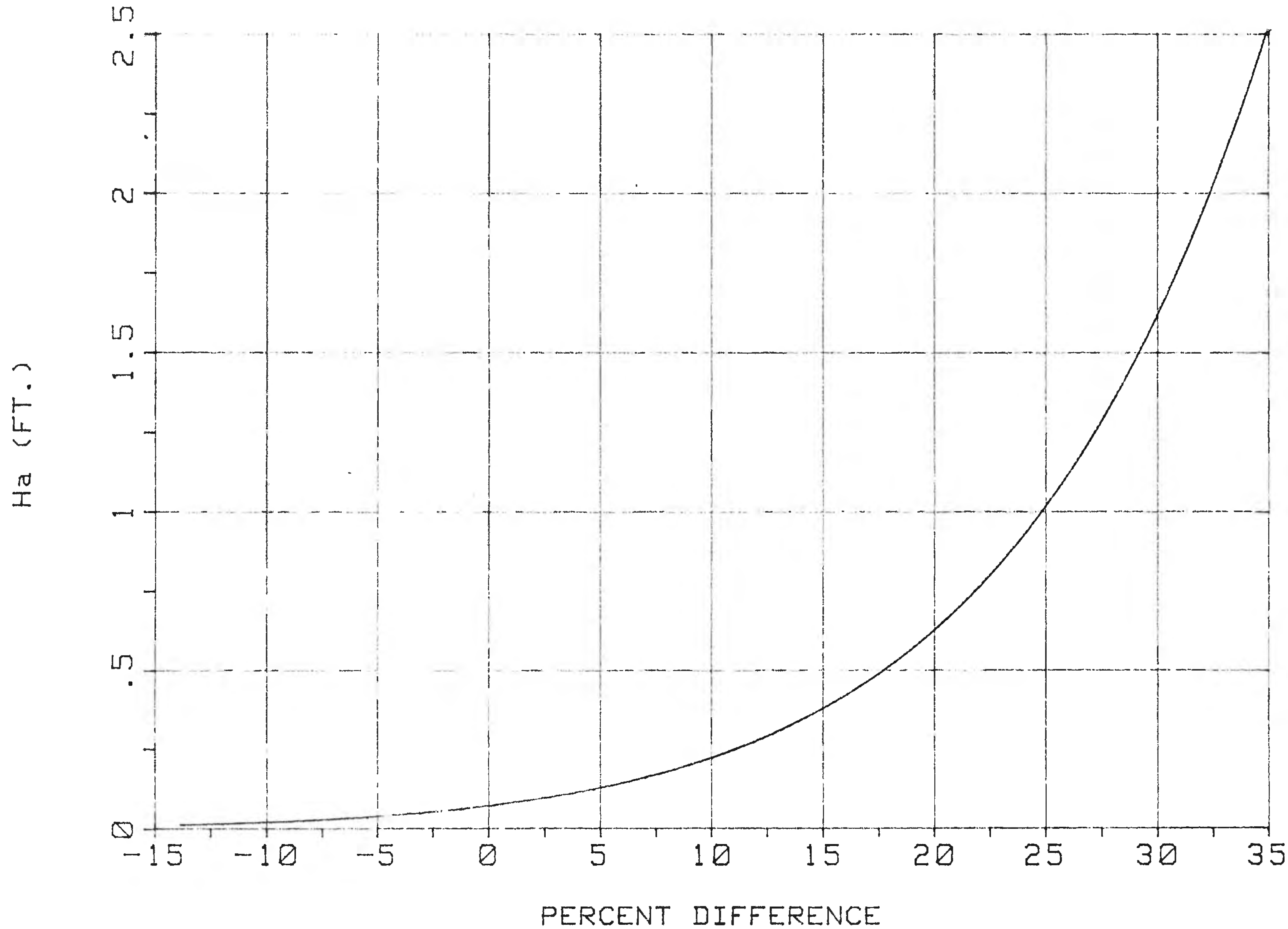

Figure 6 : Q = 2.50[illegible] Sec.-Ft.