Appendix E
Head Loss Methods and Formulas

E-l. General

This appendix shows the different methods and formulas used to determine the head losses occurring in a pumping station. For stations with complex discharge configurations and which are over 2,000-cfs total capacity, consideration should be given to performing a model test to confirm the losses. This is particularly important when the low head determines the size of the pump driver and the losses are greater than 15 percent of the total head. All losses should be determined for the maximum flow rate expected to occur for that pumping condition.

E-2. Internal Pipe Losses

a. Friction losses. The Darcy-Weisbach formula can be used to determine friction losses in circular pipes. This formula is preferable to other formulas since it takes into consideration all the variable conditions. For water temperatures above 60°F. and using the friction factors found in typical Corps of Engineers discharge pipe * systems, the following formula (in the form of Hazen and Williams) applies:

$$h_f = 0.0366\ V^{1.83} / D_{pipe}^{1.17} \qquad \text{(E-1)}$$

where

h_f = frictional resistance, ft of fluid per 100-ft length

V = velocity, fps

D_{pipe} = inside diameter of the pipe, ft

b. Bend losses. Bends are usually constructed either by fabrication of mitered cut straight pieces welded together or of cast or forged construction. Friction factor "K" can usually be obtained from various charts and tables. The inside diameter of the pipe in used to locate the correct friction factor "K." The loss for the bend is found by multiplying the "K" value by the velocity head occurring in that section of pipe.

c. Entrance, exit, and other losses. Other losses occur when a section of piping changes in diameter. These changes in size can be from something less than one pipe diameter to an infinitely greater diameter, such as a discharge into a pool or lake where the velocity downstream of the pipe is zero. Various charts and tables are available for determining the appropriate friction factor "K" for the various fittings, increasers, and reducers. Chart E-l shows the various water surfaces for open discharges from vertical tubes such as used with submersible pump installations. When using this chart, the velocity head would not be added into the system losses since this loss is expended in obtaining the height of water above the vertical pipe exit. It is also seen from the chart that the elevation of the water is also dependent on the discharge bay dimensions.

E-3. External Losses

a. General. The capacity used to determine the external head losses is usually calculated on the basis of total station capacity. An exception to this would be the loss through a single gate opening on an individual pump sump.

b. Discharge chamber losses. ***The*** head loss in a discharge chamber usually is caused by a constriction in area at its exit. This restriction is usually the stop log slots used for dewatering the chamber for repair of a flap gate during high discharge stages. A critical depth condition (Figure E-l) can occur at this location if the water level downstream of this point is at a lower elevation. The discharge chamber critical depth is determined using the formula shown on Chart E-2. This formula applies * when a free discharge exists beyond the stop log slot at the exit of the discharge chamber. In order to obtain flow in the discharge chamber, a head of water is required at the opposite end of the chamber. This head of water is added to the water elevation caused by either the critical depth condition at the stop log slots, or the downstream water elevation, whichever is greater. The head of water is equal to the velocity head occurring with the depth of water at the stop log slots. An example of calculation of the critical depth and the resulting discharge chamber depth is shown below. It can be seen that the real head on a pump may be greater because of the artificial head created by the losses in the discharge chamber. It is required to determine which is greatest, the water level in the discharge chamber created by the restriction or the center-line elevation of the flap gates. The center-line elevation of the flap gate is used to determine the low static head whenever it is higher than the water level, in the discharge chamber, occurring for that pumped flow rate. The slope of the water surface in the chamber will be greatest at the opposite end from the constriction, and usually not at the exact location of all the discharge flap gates. For purposes of head determination, it is assumed that the greatest water level occurring in the discharge chamber will be effective for all the pump discharges.

c. Trashrack losses. Head loss through the trashracks should be less then 6 inches for a properly designed rack that is raked regularly. A head loss value of 6 inches will be used when determining the trashrack portion of the total external losses. It is possible to exceed this value when the rack becomes partially clogged with debris; therefore the structure design of the rack should be in accordance with EM 1110-2-3104. In unusual cases where the design of the rack is such that for a clean rack the losses would be greater than 6 inches, the calculated loss plus a 6-inch margin should be used for the head loss.

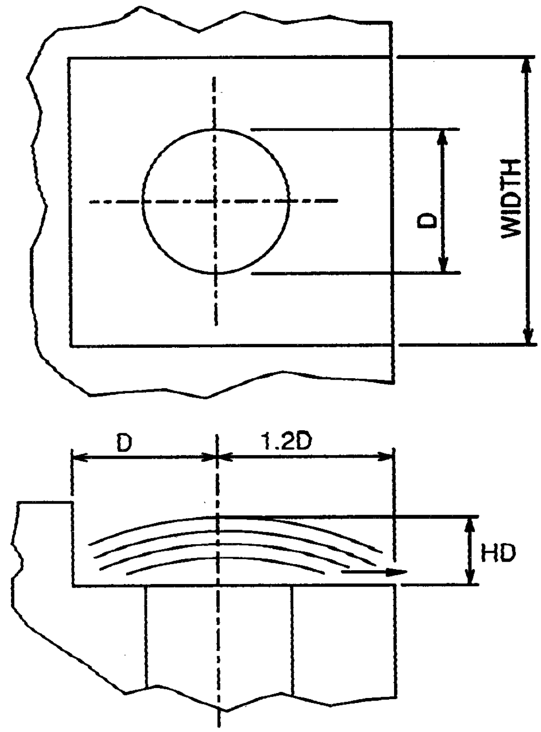
d. Gate opening losses. The head loss through gate openings is assumed to be equal to the velocity head that occurs for the gate opening. If multiple gate openings occur in the water path to the pumps, then a loss would occur at each gate opening and be additive.

*

$HD_{ft} = 0.0001(m)(Q) + b$

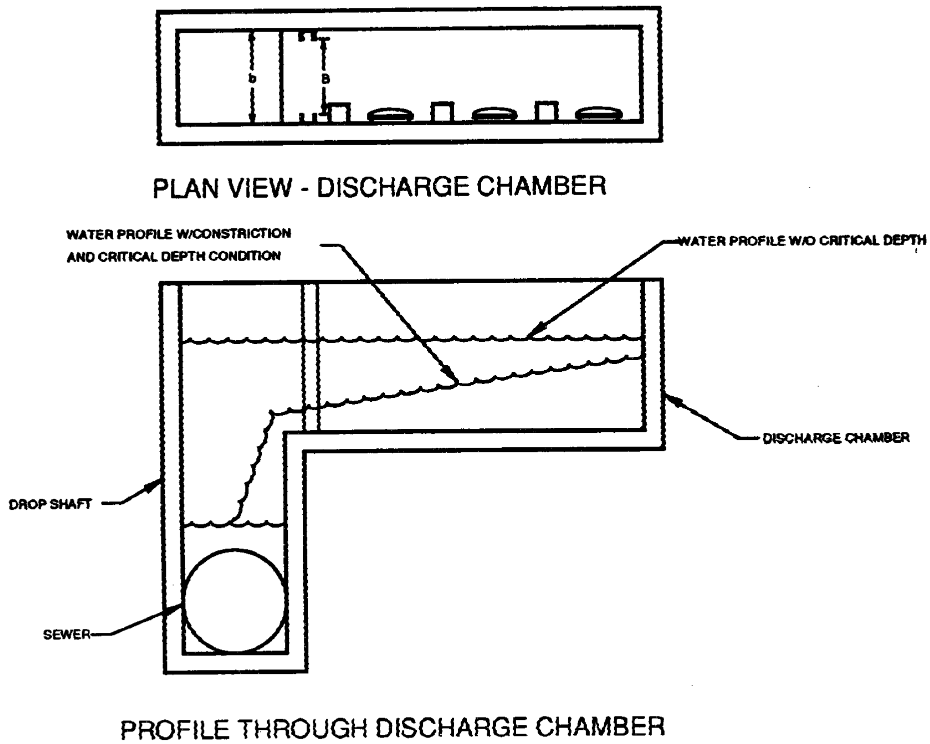
Where m = Value from table
Q = Pump capacity in GPM
b = Value from table
HD = Water height above floor in feet

WIDTHS = 1.5D, 2.0D, 2.5D & 3.0D
D = TUBE DIAMETER



TUBE DIA. in. nom.	DISCHARGE WIDTH - VALUES OF m AND b								TUBE DIA. mm.
	1.5 D		2.0 D		2.5 D		3.0 D		
	m	b	m	b	m	b	m	b	
28	1.65	0.33	1.24	0.25	1.36	0.13	1.24	0.07	700
32	1.36	0.33	1.24	0.23	1.03	0.13	1.03	0.07	800
40	0.83	0.39	0.89	0.30	0.91	0.16	0.78	0.07	1000
48	0.68	0.62	0.68	0.43	0.52	0.26	0.52	0.07	1200
56	0.52	0.72	0.52	0.82	0.52	0.30	0.39	0.16	1400
64	0.41	0.82	0.41	0.66	0.41	0.33	0.41	0.16	1600

Chart E-1. Open tube losses



B = WIDTH BETWEEN CONSTRICTION, FT.

b = WIDTH UPSTREAM OF CONSTRICTION, FT.

g = 32.2 FT /SEC ^{2}

A = AREA OF FLOW IN DISCHARGE CHAMBER, FT ^{2}

A_C = AREA OF FLOW WITH CRITICAL DEPTH CONSTRICTION, FT ^{2}

H_V = VELOCITY HEAD, FT.

k = COEFFICIENT OF CONTRACTION, (k) = 0.78

V_C = VELOCITY OF FLOW AT CONSTRICTION, WITH CRITICAL DEPTH CONDITIONS, FT/SEC

V = VELOCITY OF FLOW WHEN CRITICAL DEPTH CONDITION DOES NOT OCCUR, FT/SEC

Q = DESIGN FLOW RATE (HIGH HEAD AND LOW HEAD), CFS

Y_C = DEPTH OF FLOW AT CONSTRICTION, FT

H_C = WATER ELEVATION AT CONSTRICTION IN DISCHARGE CHAMBER CAUSED BY CRITICAL DEPTH CONDITION

H_D = WATER ELEVATION IN DISCHARGE USED TO DETERMINE PUMPING CONDITIONS

Figure E-1. Discharge chamber critical depth

DISCHARGE CHAMBER CRITICAL DEPTH

The determination of total head on the pump requires determination of water elevation in the discharge chamber. Three different head conditions are considered.

1. During pump operation back-up water does not exceed the center of the flap gate.

2. Water elevation in drop shaft next to discharge chamber is below elevation of the critical depth water level. Elevation of water back-up is above the center of the flap gate.

3. Water elevation in drop shaft is higher than water elevation due to critical depth condition.

The total head is then based on the greatest depth at the constriction plus the velocity head required to maintain flow.

The following is a typical computation to determine total head for discharge chamber type pump station. The computations are based on the layout shown on Figure E-1.

Given Conditions:

B = 4.5 ft.	Discharge chamber floor elevation at constriction = 413.0
b = 5.0 ft.	
Q_L = 177 cfs	Drop shaft water elevation due to sewer losses beyond drop shaft with 177 cfs flowing = 417.0
Q_H = 93.4 cfs	
k = 0.78	Drop shaft water elevation with 93.4 cfs flowing = 431.0
	Elevation of flap gate centerline = 416.75

Computations for water levels as result of critical depth -

STEP 1. Determine ratio of width at constriction to channel width upstream.

Ratio = B/b = 4.0 ft./5.0 ft. = 0.9

STEP 2. Determine Y_c.

$$Y_c = (Q^2/(k^2 \times b^2 \times g))^{1/3}$$

$$= (177^2/(0.78)^2(5.0)^2(32.2))^{1/3} = 3.9 \text{ ft.}$$

STEP 3. Determine velocity of flow at the constriction.

$$V_c = [(Y_c)(g)]^{1/2} = 11.2 \text{ ft/sec}$$

Chart E-2. Critical depth condition (Sheet 1 of 3)

STEP 4. Determine critical area of flow at the constriction.

$A_c = Q_L/V_c$ = 177 cfs/11.2 ft/sec = 15.8 ft/sec

STEP 5. Determine the velocity head based on the velocity occurring at the constriction.

$H_V = Y_c/2$ = 3.9 ft/2 = 1.95 ft.

STEP 6. Determine the maximum elevation of water in the discharge chamber at constriction with critical depth condition.

H_c = Elev. of discharge chamber floor + $1.5Y_c$

= 413.0 + 1.5(3.9 ft.) = 418.8

STEP 7. Water elevation in drop shaft with low river elevation and flow rate of 177 cfs is 417.0.

STEP 8. Determine water elevation in discharge chamber with constriction of flow.

H_c = Floor elev. at constriction + depth of flow at constriction + velocity head based on flow at constriction

= 413.0 + Y_c + $Y_c/2$

= 413.0 + 3.9 + 1.95

= 418.8

STEP 9. This elevation (418.8) is greater than the water level in the drop shaft (417.0), therefore it is used to determine head loss if it is higher than the centerline of the flap gate.

STEP 10. When the elevation of water in the drop shaft is greater then the water elevation as result of a critical depth condition at the constriction, the water level in the discharge chamber is only dependent on the drop shaft water elevation and the resultant velocity head.

The discharge chamber water elevation would equal the drop shaft water elevation + the velocity head.

Water elevation in drop shaft = 431.0

Chart E-2. (Sheet 2 of 3)

Velocity at constriction, V_c

V_c = Flow rate (cfs)/(Drop shaft elev. - Floor elev.)(B ft)

= 93.4/(431.0 - 413.0)(4.5)

= 1.15 ft/sec

Velocity Head = $(V_c)^2/2g$

= $(1.15)^2/(2)(32.2)$

= 0.02 ft. => Negligible

Therefore, Elevation 431.0 would be used for head computations.

Chart E-2. (Sheet 3 of 3)