

**FHWA Headloss in InfoWorks ICM**  
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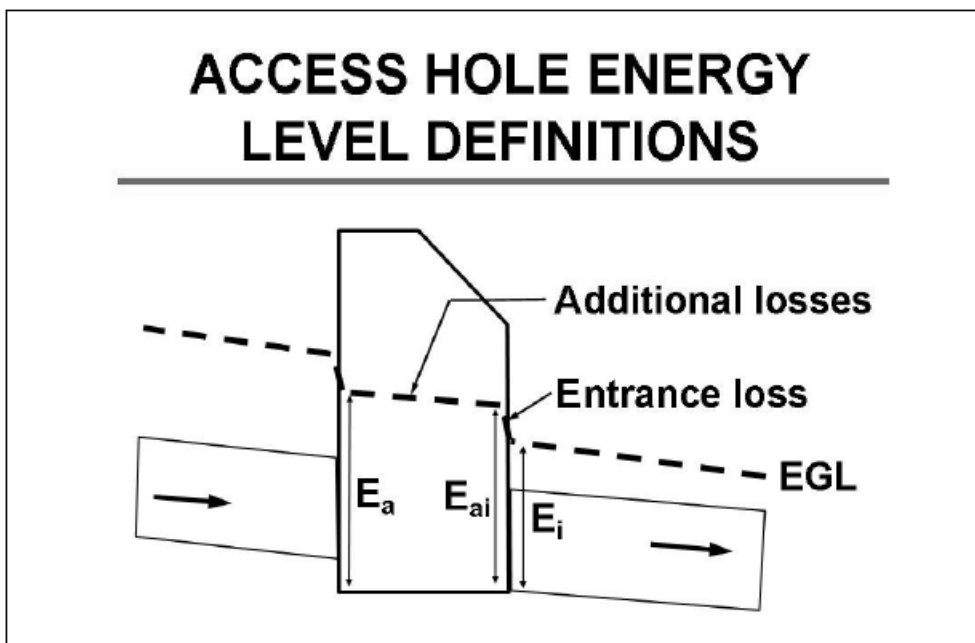
## 1. Introduction

This document describes the FHWA headloss type, implemented in InfoWorks ICM version 4.0 onwards. The implementation is based on section 7.1.6.7 of HEC 22 (Reference 1.)

The FWHA headloss type is implemented simply by specifying 'FWHA' for the upstream or downstream headloss type for a conduit. Any manholes connected to a pipe for which the FWHA method is being used should have the relevant 'bench method' property defined. The FWHA can only be used on 'full solution' closed conduits, i.e. not pressure pipes, open channels, rivers or ancillary structures. It also can only be used with manholes, i.e. no storage or break nodes.

The method is applied in three steps:

1. Determine the initial access hole energy level ( $E_{ai}$ )
2. Adjust  $E_{ai}$  to account for inflow angle(s), benching and plunging flows to provide final calculated energy level ( $E_a$ )
3. Calculate the exit loss associated with each incoming pipe.



**Figure 1** Access Hole Energy Level Definitions

The Energy Grade Line (EGL) corresponding to these three steps is shown in Figure 1, which is taken from Figure 7-5 of Reference 1.

## 2. Step 1, Calculation of $E_{ai}$

$$E_{ai} = \max(E_{aio}, E_{ais}, E_{aiu}) \quad (7-14)$$

where:

- $E_{aio}$  = Estimated access hole energy level for outlet control (full and partial flow)
- $E_{ais}$  = Estimated access hole energy level for inlet control (submerged)
- $E_{aiu}$  = Estimated access hole energy level for inlet control (unsubmerged)

Therefore the first task is to determine whether the outgoing pipe is submerged or unsubmerged.

$$E_{aio} = E_i + H_i \quad (7-15)$$

where:

$H_i$  = Entrance loss assuming outlet control, calculated using Equation 7-16

$$H_i = K_i (V^2 / 2g) \quad (7-16)$$

where:

$K_i$  = Entrance loss coefficient = 0.2, dimensionless<sup>(96)</sup>

Therefore  $E_{aio}$  = upstream water depth +  $1.2 v^2/2g$

#### *Estimated Energy Level for Inlet Control: Submerged*

Inlet control calculations employ a dimensionless ratio adapted from the analysis of culverts referred to as the discharge intensity. The discharge intensity is described by the Discharge Intensity (DI) parameter, which is the ratio of discharge to pipe dimensions:

$$DI = Q / [A (gD_o)^{0.5}] \quad (7-17)$$

where:

$A$  = Area of outflow pipe,  $m^2$  ( $ft^2$ )

$D_o$  = Diameter of outflow pipe,  $m$  ( $ft$ )

The submerged inlet control condition uses an orifice analogy to estimate the energy level ( $E_{ais}$ ) (Equation 7-18). Derivation of Equation 7-18 used data with discharge intensities less than or equal to 1.6.

$$E_{ais} = D_o (DI)^2 \quad (7-18)$$

#### *Estimated Energy Level for Inlet Control: Unsubmerged*

Laboratory analyses<sup>(94, 95)</sup> describe that unsubmerged inlet control conditions are associated with discharge intensities (DI) in a 0.0 to 0.5 range (this is not to suggest that the equation is limited to this range). The unsubmerged inlet control condition uses a weir analogy to estimate the energy level ( $E_{aiu}$ ):

$$E_{aiu} = 1.6 D_o (DI)^{0.67} \quad (7-19)$$

InfoWorks ICM includes an option to present which headloss condition is currently being used, throughout a simulation. To apply it, the 'time series log' box must be ticked under 'diagnostics', when a simulation is scheduled. The results will then include a conduit parameter called 'status' which can be graphed or tabulated.

The status results and their meanings are presented in Table 1:

**Table 1 Headloss Status Condition Descriptions**

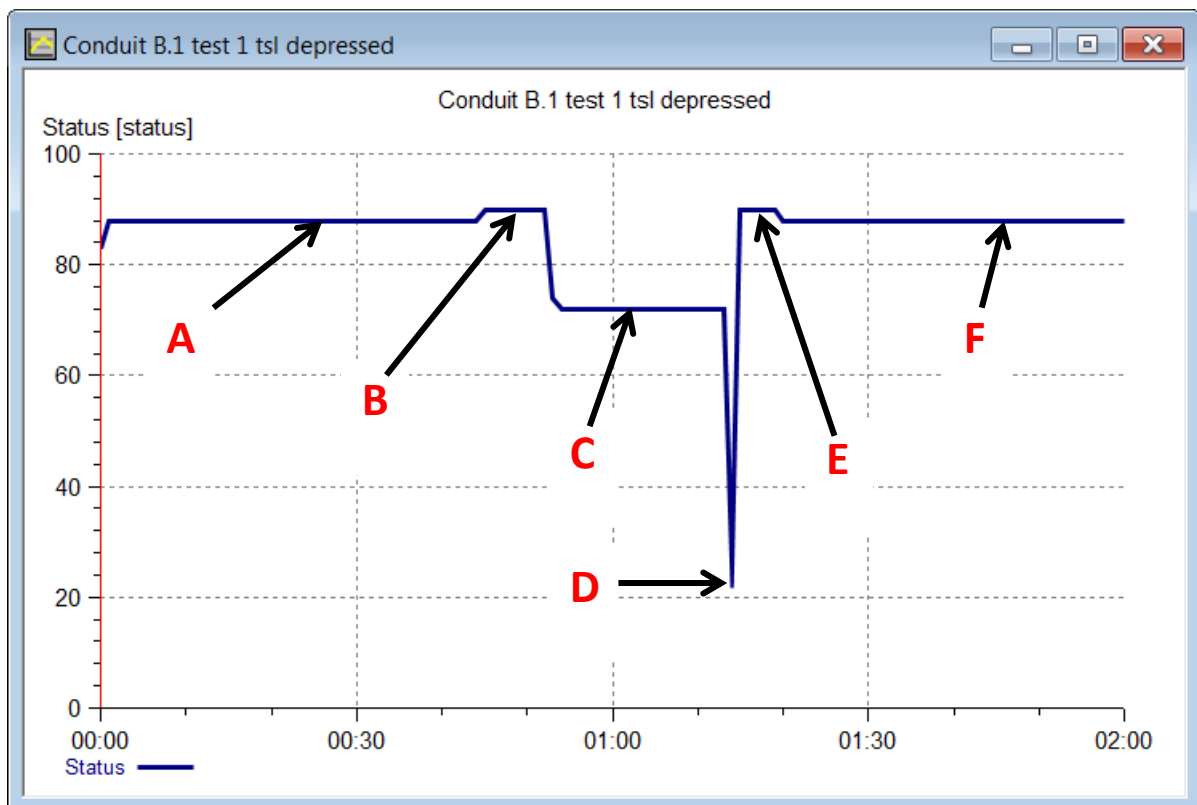
Status	Headloss condition
0	Simple headloss
1	Free discharge (subcritical)
2	Free discharge (full pipe, subcritical)
3	Reset (depth below base depth)
4	Jet (full pipe, critical flow)
5	Free discharge (normal flow)
6	Free discharge (full pipe, normal flow)
7	FHWA inflow pipe (not plunging)
8	FHWA outlet control ( $E_{aio}$ )
9	FHWA submerged inlet control ( $E_{ais}$ )
10	FHWA unsubmerged inlet control ( $E_{aiu}$ )

One status result is used to represent the headloss condition at both the up and downstream ends of a pipe. This is achieved by multiplying the downstream headloss by a large number, in this case 16.

Therefore:

$$\text{Conduit status} = \text{upstream status} + (16 \times \text{downstream status})$$

An example of how conduit status is determined, is presented in Figure 2 below, using the data from Appendix A.



**Figure 2 Annotated Status Graph**

The values corresponding to notations A – F in Figure 2, are presented in Table 2:

**Table 2 Conduit Status Calculated Values**

Condition	Conduit Status	Upstream condition	Downstream condition
A	88	8	5
B	90	10	5
C	72	8	4
D	26	10	1
E	90	10	5
F	88	8	5

Calculations showing how  $E_{ai}$  is derived for upstream conditions 8 and 10 are presented in Appendices A.1 and A.2.

### 3. Step 2, Adjustment of $E_{ai}$ to Provide $E_a$

As previously stated,  $E_{ai}$  is adjusted to account for inflow angle(s), benching and plunging flows to provide final calculated energy level ( $E_a$ ). These processes are discussed individually in the following chapters.

#### 3.1 Adjustment for Inflow Angle

All inflows are resolved in to a single angle  $\Theta_w$ .

$$\theta_w = \sum (Q_J \theta_J) / \sum Q_J \quad (7-22)$$

where:

- $Q_J$  = Contributing flow from inflow pipe,  $m^3/s$  ( $ft^3/s$ )
- $\theta_J$  = Angle measured from the outlet pipe (180 degrees is a straight pipe)

The coefficient  $C_\theta$  is then calculated at follows.

$$C_\theta = 4.5 (\sum Q_J / Q_o) \cos (\theta_w / 2) \quad (7-23)$$

where:

- $Q_o$  = flow in outflow pipe,  $m^3/s$  ( $ft^3/s$ )

Finally the additional headloss associated with the angled flow is calculated from the equation:

$$H_\theta = C_\theta ( E_{ai} - E_i ) \quad (7-24)$$

An example of these calculations is presented in Appendix A.3.

#### 3.2 Adjustment for Benching

Benching adjustments are taken from the following table, which is again taken from Reference 1.

**Table 7-6. Values for the Coefficient,  $C_B$ .**

Floor Configuration	Bench Submerged*	Bench Unsubmerged*
Flat (level)	-0.05	-0.05
Depressed	0.0	0.0
Half Benched	-0.05	-0.85
Full Benched	-0.25	-0.93
Improved	-0.60	-0.98

\*A bench submerged condition has the properties of  $(E_{ai}/D_o) > 2.5$  and bench unsubmerged condition has the properties of  $(E_{ai}/D_o) < 1.0$ . Linear interpolation between the two values is used for intermediate values.

Note that the water level cannot go below  $E_{ai}$ .

An example of this relatively simple calculation is presented in Appendix A.4.

### 3.2 Adjustment for Plunging

The adjustment is largely based on the invert of the incoming pipe(s) above the invert of the outgoing, as follows:

The method defines a relative plunge height ( $h_k$ ) for a plunging pipe (denoted by the subscript  $k$ ) as:

$$h_k = (z_k - E_{ai}) / D_o \quad (7-25)$$

This relative plunge height allows determination of the plunging flow coefficient ( $C_P$ ):

$$C_P = \sum (Q_k h_k) / Q_o \quad (7-26)$$

As the proportion of plunging flows approaches zero,  $C_P$  also approaches zero. Equation 7-25 and Equation 7-26 are limited to conditions where  $z_k < 10D_o$ . If  $z_k > 10D_o$  it should be set to  $10D_o$ .

The additional plunging inflow energy loss is given by:

$$H_P = C_P (E_{ai} - E_i) \quad (7-27)$$

Once again as example is given in Appendix A.5.

## 4. Step 3, Calculation of Exit Losses

The fundamental assumption is that the velocity in the access chamber is zero and therefore, for non-plunging pipes:

$$HGL_a = EGL_a$$

$$EGL_o = EGL_a + H_o \quad (7-31)$$

where:

$$H_o = \text{Inflow pipe exit loss, calculated using Equation 7-32}$$

Exit loss is calculated in the traditional manner using the inflow pipe velocity head since a condition of supercritical flow is not a concern on the inflow pipe. The equation is as follows:

$$H_o = K_o (V^2 / 2g) \quad (7-32)$$

where:

$$K_o = \text{Exit loss coefficient} = 0.4, \text{ dimensionless}^{(96)}$$

Given

$$EGL_o = HGL_o + v^2/2g$$

$$HGL_o = HGL_a - 0.6 v^2/2g$$

## Appendix A Example Calculations

### A.1 30 minutes in to the simulation (Condition A from Figure 2):

Pipe is unsubmerged, therefore:

$$E_{ai} = \max(E_{aio}, E_{aiu})$$

$$\text{Upstream depth} = 0.157 \text{ m}$$

$$\text{Upstream velocity} = 1.666 \text{ m/s}$$

$$E_{aio} = 0.157 + 1.2 (1.666^2 / 19.62) = 0.326 \text{ m}$$

$$\text{Pipe diameter} = 275 \text{ mm, therefore } A = 0.0594 \text{ m}^2$$

$$\text{Flow} = 0.05823 \text{ m}^3/\text{s}$$

Therefore, from (7-17)

$$DI = 0.05823 / 0.0594 (9.81 (0.275)^{0.5}) = 0.5969$$

From (7-19)

$$E_{aiu} = 1.6 \times 0.275 \times (0.5969)^{0.67} = 0.311 \text{ m}$$

Therefore  $E_{aio} > E_{aiu}$

$$\text{Level in manhole} = \text{invert level (28 m)} + 0.326 = 28.326 \text{ m}$$

This matches simulation results.

### A.2 48 minutes in to the simulation (Condition B from Figure 2):

Pipe is unsubmerged, therefore:



$$E_{ai} = \max (E_{aio}, E_{aiu})$$

$$\text{Upstream depth} = 0.225 \text{ m}$$

$$\text{Upstream velocity} = 1.810 \text{ m/s}$$

$$E_{aio} = 0.225 + 1.2 (1.810^2 / 19.62) = 0.425 \text{ m}$$

$$\text{Flow} = 0.09404 \text{ m}^3/\text{s}$$

Therefore, from (7-17)

$$DI = 0.09404 / 0.0594 (9.81 (0.275)^{0.5}) = 0.9639$$

From (7-19)

$$E_{aiu} = 1.6 \times 0.275 \times (0.9639)^{0.67} = 0.429 \text{ m}$$

Therefore  $E_{aiu} > E_{aio}$

$$\text{Level in manhole} = \text{invert level (28 m)} + 0.429 = 28.429 \text{ m}$$

This matches simulation results.

### A.3. 90 degree bend (Other conditions same as example A.2.)

$$\text{Upstream depth} = 0.222 \text{ m}$$

$$\text{Upstream velocity} = 1.810 \text{ m/s}$$

$$\text{Flow} = 0.09287 \text{ m}^3/\text{s}$$

$$E_{ai} = 0.426 \text{ m}$$

$E_i$  = upstream depth + velocity component

$$= 0.222\text{m} + (1.81^2 / 2g) = 0.389 \text{ m}$$

Angle = 90 degrees.

$$\text{Therefore } \cos (90/2) = 0.707$$

$$\text{Therefore } C_\theta = 4.5 \times 0.707 = 3.182$$

$$\text{Therefore } H_\theta = 3.182 (0.426 - 0.388) = 0.117$$

$$\text{Water level} = 28 + 0.429 + 0.118 = 28.543$$

Simulation result = 28.544

### A.4. "Improved" Benching (Other conditions same as example A.3.)

$$E_{ai} = 0.429 \text{ m}$$

Pipe diameter = 275 mm

Therefore  $E_{ai} / D_0 = 1.56$

This is between the submerged condition of 2.5 and unsubmerged condition of 1.0. A value of -0.84 is therefore derived by linear interpolation (between the values of -0.60 and -0.98)

$$H_B = -0.84 (0.429 - 0.392) = -0.031.$$

Therefore revised level =  $28.544 - 0.031 = 28.513$

Simulation result = 28.514

#### **A.5. Plunging Inflow (Other conditions same as example A.2.)**

Invert of incoming pipe = 29 m.

Therefore  $z_k = 1.0$  m

$$H_k = (1 - 0.429) / 0.275 = 2.076 \text{ m}$$

Therefore  $>10D_0$  limitation does not apply

100 % of flow comes from this pipe. Therefore  $C_p = 2.076$

$$H_p = 2.076 (0.429 - 0.392) = 0.077$$

Therefore level =  $28.429 + 0.077 = 28.505$

Simulation result = 28.513.

#### **References**

1. U.S Department of Transportation, Federal Highway Administration, Hydraulic Engineering Circular No. 22, Third Edition, Urban Drainage Design Manual, Publication No. FHWA-NHI-10-009, September 2009.