Interactive hydraulic analysis for storm drain pipe systems

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An interactive hydraulic analysis computer program has been developed to aid hydraulic engineers in designing storm drain pipe systems. The entire storm drain system is analysed for both supercritical and subcritical flow effects. By comparing the specific force (pressure plus momentum) for each pipe reach, the hydraulic grade line (HGL) and energy grade line (EGL) for the entire system can be calculated. Using this approach, both pressure and nonpressure storm drain system hydraulics can be evaluated simultaneously. Thus, a more economic storm drain pipe system can be designed by the hydraulic engineer, with the speed and computational accuracy afforded by the computer.

Key Words: gradually varied flow profile, supercritical flow, subcritical flow, pressure plus momentum, storm drain pipe system, hydraulic jump, pressure flow, open channel flow

INTRODUCTION

A strategy for the design of the storm drain and the selection of pipe sizes is to attempt to achieve pressure flow conditions whenever possible. This strategy is especially useful in regions where the land topography has a mild gradient (approximately 0.0010 to 0.0040 ft/ft). The resulting system would be somewhat optimized in that the design consideration of the hydraulic grade line would closely conform to the maximum allowable value while providing a reasonable design for flood protection purposes.

The typical design of any storm drain system requires two basic procedures. Assuming the system has been laid out in plan, with all inlets located and the rate of inflow to each determined, the first steps are to sum the rate of flow in each pipe, select all pipe sizes and calculate the friction loss in each length of pipe. The second step is to calculate the change in hydraulic gradient (ΔY) at each junction. The hydraulic grade line elevation is determined at the branch point of each junction or inlet and the change (ΔY) at the junction is added algebraically, working progressively upstream or downstream along each pipeline. The more practical method proceeds downstream keeping the hydraulic grade line just below the street surface but low enough to accept surface flows. The last pipeline must then be sized so the hydraulic grade line is at or above the control hydraulic gradient elevation. In general, most of the storm drain analysis proceeds upstream when the depth of flow is greater than critical depth, and proceeds downstream when the depth of flow is less than critical depth. In a pressure flow system, the analysis always proceeds upstream. Also note that the storm drain analysis proceeds upstream from the downstream control depth is the more correct method but is more time consuming.

In the subject computer program, the hydraulic analysis first proceeds upstream. Therefore, the water depth is assumed to be greater than the critical depth in each drainage reach. A second analysis is then made by calculations in the downstream direction, where the depths are less than or equal to the critical depth in each drainage reach. Finally, the pressure plus momentum values for each of the two analyses are compared to determine the EGL and HGL for the entire storm drain system. Pressure flow, nonpressure flow, hydraulic jumps, and minor losses in each drainage reach can be determined individually.

FUNDAMENTALS OF HYDRAULICS

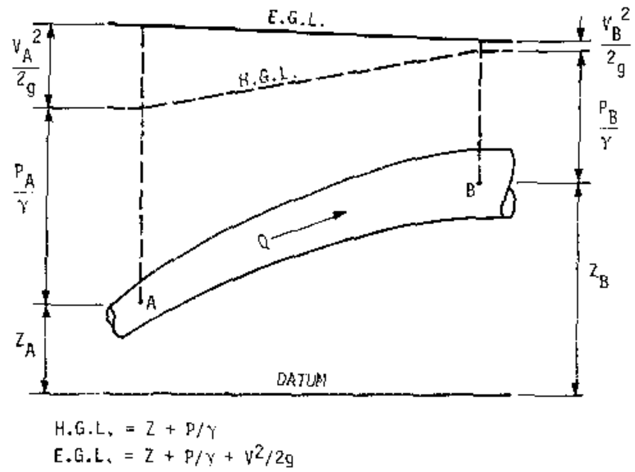
Hydraulic grade line and energy grade line

For any point in the fluid, the summation of the elevation plus the pressure head is known as the piezometric head. The piezometric head represents the level to which liquid will rise in a piezometer. The line drawn through the top of a series of piezometer columns is known as the hydraulic grade line (HGL). The energy grade line (EGL) is determined by the sum of the HGL and the velocity head ($V^2/2g$) such as is shown in Fig. 1a.

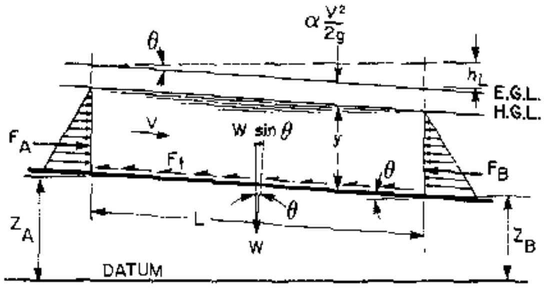
Specific energy

In open channel flow, the specific energy S_E, is given by

$$S_E = y\cos^2\theta + \alpha V^2/2g \qquad (1)$$



(a) Pressure flow system



(b) Uniform flow in open channel

Fig. 1. HGL and EGL for pressure and nonpressure flow system

where

y = vertical depth of flow
θ = angle of the longitudinal bed profile with respect to the horizontal. (In most cases θ is small, therefore $\cos^2\theta = 1$)
α = kinetic energy correction factor. This is equal to one when the velocity distribution is uniform
V = average flow velocity
g = gravitational acceleration

Given the flow rate (Q), and cross section flow area (A), and for $\cos^2\theta = 1$,

$$S_E = y + Q^2/2gA^2 \tag{2}$$

$$(S_E - y)A^2 = Q^2/2g = \text{constant} \tag{3}$$

From equation (3), it is clear that the specific energy curve of Fig. 2 has the two asymptotes of $y = S_E$, and $y = 0$.

The specific force

Consider a steady, uniform, incompressible flow in an open channel between channel section A to section B, and apply Newton's second law of motion. The second law of motion states that the change of momentum per unit time in the body is equal to the resultant of all the external forces that are acting on the body (see Fig. 1b). Thus for a fixed control volume,

$$Q(\beta_B V_B - \beta_A V_A) = P_A - P_B + W\sin\theta - F_f \tag{4}$$

where

β = momentum correction factor
P_A and P_B = resultant pressures acting on section A and B, respectively
W = equivalent weight of the fluid pressure enclosed between sections A and B
F_f = total external forces (including friction) along the wetted boundary of the channel between section A and section B
θ = angle of channel slope with respect to the horizontal

The pressure forces are calculated by

$$P_A = \gamma A_A h_A, \qquad P_B = \gamma A_B h_B \tag{5}$$

where

γ = the specific weight of the water
h = the distance to the centroid of the cross section below the water surface

If the difference of $W\sin\theta - F_f$ can be neglected and $\beta_1 = \beta_2 = 1$, then equation (4) can be simplified as

$$A_A h_A + Q^2/gA_A = A_B h_B + Q^2/gA_B \tag{6}$$

Both sums of the terms in (6) involve identical components, and can be grouped together as the specific force, F_S. That is,

$$F_S = Ah + Q^2/gA \tag{7}$$

The specific force curve (Fig. 3) is similar in some of its characteristics to the specific energy curve (Fig. 2).

LOSSES

Head losses on the storm drain system are based on Los Angeles County Road Department, Design Manual (1972), Los Angeles County Flood Control District, Design Manual: Hydraulic (1970), and Orange County Flood Control District, Design Manual: Channel Hydraulics and Structures (1972).

Friction losses

Friction losses for pipeflow conditions are computed from Manning's equation for steady flow

$$Q = \frac{1.486}{n} AR^{2/3} S_f^{1/2} \tag{8}$$

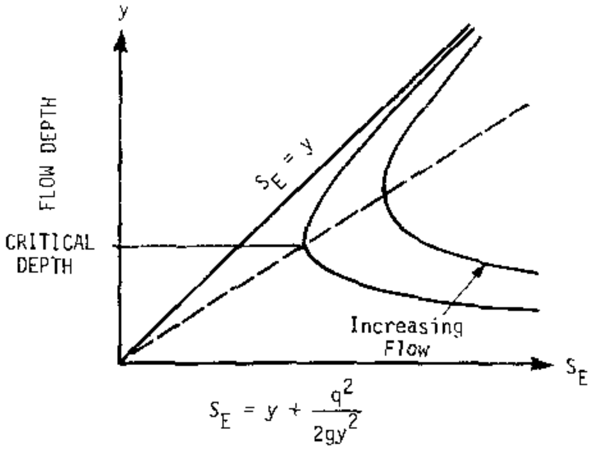


Fig. 2. The specific energy curve

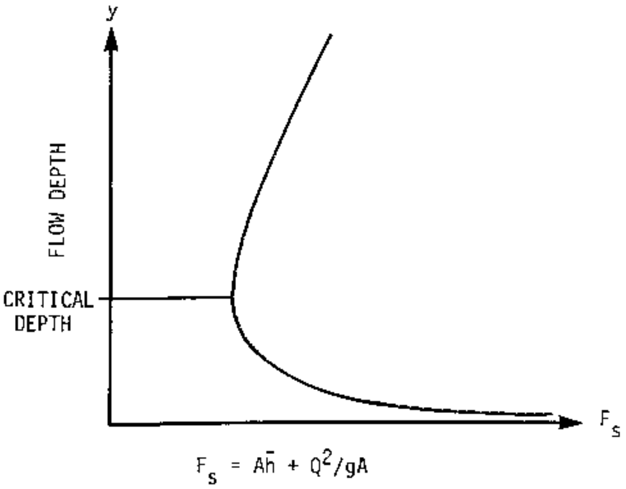


Fig. 3. The specific force curve

Table 1. Typical, Manning's friction factors

Conduit description	*n*
Reinforced concrete pipe (RCP)	0.013
Asbesto cement pipe (ACP)	0.012
Corrugated metal pipe (CMP)	0.024
Asphalt lined CMP	0.015

where

Q = flow rate
n = friction factor
A = flow area of pipe
R = hydraulic radius
S_f = friction slope

For storm drain design purposes, the friction factor is assumed to be a constant (regardless of the flow rate). Typical values for the friction factor are given in Table 1. The friction losses, H_f, can be estimated as

$$H_f = S_f L \tag{9}$$

where L is the length of pipe.

Manhole losses

Manhole structures are generally constructed along the storm drain line in order to provide an adequate maintenance access to the pipeline. The losses, H_m, due to the passage of flow through the manhole can be estimated as

$$H_m = K_m \cdot H_v \tag{10}$$

where

K_m = manhole loss coefficient
H_v = flow velocity head

In this calculation, the pipe diameter is assumed to not change at the manhole.

Bend and angle-point losses

Bend and angle-point losses are usually limited to pressure flow situations since the losses evident in properly designed open channels are typically minor. Bend and angle point losses are additive to frictional losses and are usually equated with velocity head by $H_L = K \cdot H_v$.

The bend losses, H_b, can be estimated as

$$H_b = 0.25 \cdot K_b \cdot H_v \tag{11}$$

where $K_b = \sqrt{\Delta/90^\circ}$ and Δ is the central bend angle in degrees (see Fig. 4).

The angle-point losses, Hap, can be estimated as

$$\mathrm{Hap} = \mathrm{Kap} \cdot H_v \tag{12}$$

where Kap is a coefficient which is experimentally determined. The coefficient Kap is assumed to be a function of the central angle (see Fig. 5) as shown in Table 2.

Sudden pipe-reduction (contraction) losses

The sudden contraction of a pipe flow is shown in Fig. 6. A convenient procedure for estimating the sudden contraction losses, H_c, is to assume the energy head loss to be a function of the downstream velocity head, H_{v2}, by

$$H_c = K_c \cdot H_{v2} \tag{13}$$

where K_c is a coefficient related to the ratio of downstream and upstream pipe flow area $A2/A1$ given by Table 3.

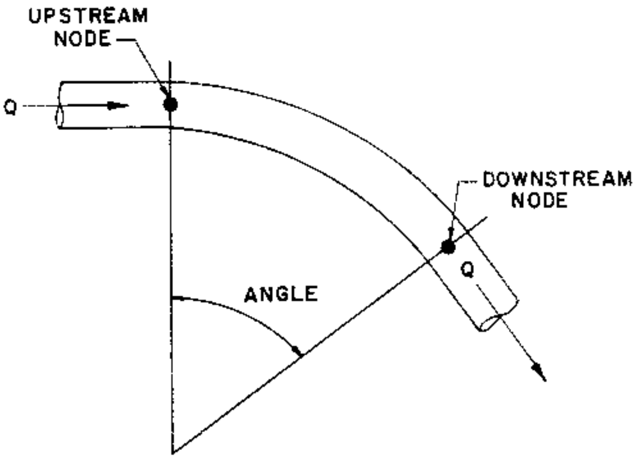


Fig. 4. Bend loss model geometry

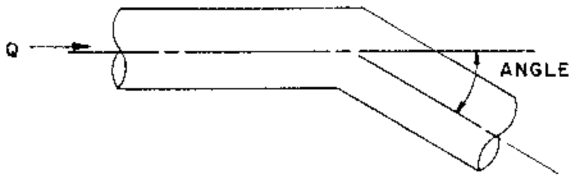


Fig. 5. Angle point loss model geometry

Fig. 6. Sudden contraction model geometry

Table 2. Typical values of Kap

Angle (degrees)	Kap	Angle (degrees)	Kap
1	0.005	10	0.030
2	0.008	12	0.037
3	0.011	15	0.047
4	0.014	20	0.067
5	0.017	25	0.090
6	0.020	30	0.115
7	0.022	35	0.146
8	0.024	40	0.148
9	0.027	45	0.234

Table 3. Typical values of K_c

$A^2/A1$	K_c
0.10	0.46
0.20	0.41
0.30	0.36
0.40	0.30
0.50	0.24
0.60	0.18
0.70	0.12
0.80	0.06
0.90	0.02
1.00	0.00

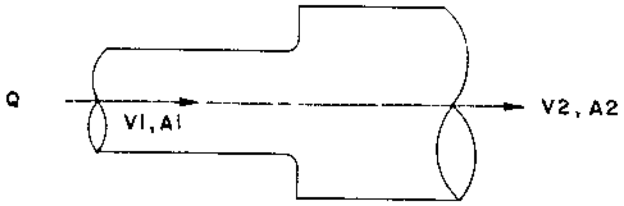


Fig. 7. Sudden enlargement model geometry

Sudden pipe-enlargement losses

The energy head loss due to a sudden enlargement of pipe size (see Fig. 7), H_e, is given by

$$H_e = \frac{(V1 - V2)^2}{2g} \tag{14}$$

where $V1$ is the upstream flow velocity and $V2$ is the downstream flow velocity.

Transition losses

Abrupt changes in pipe size are accomplished by high energy losses. In order to reduce the losses due to a sudden expansion or contraction, structures may be designed which provide for a smooth transition for the change in pipe size. The transition losses, H_t, can be estimated as a function of the change in the velocity head due to the change in pipe size by

$$H_t = \begin{cases} K_t \cdot (H_{v2} - H_{v1}) & \text{for } H_{v2} > H_{v1} \\ K_t \cdot (H_{v1} - H_{v2}) & \text{for } H_{v1} > H_{v2} \end{cases} \tag{15}$$

where K_t is the transition losses coefficient. Equation (15) is assumed to apply when the transition structure wall of convergence or divergence is less than 5.75 degrees. For angle of convergence or divergence greater than 5.75 degrees, transition losses are computed by the emperical relationship

$$H_t = 3.5 \cdot (\mathrm{Tan}(0.00872665 \cdot \mathrm{delta}))^{1.22} \tag{16}$$

where delta (see Fig. 8) is the total transition angle which is equal to twice the angle of convergence or divergence.

Friction losses due to the transition structure are also included in the transition losses.

Junction losses

The junction losses due to the confluence of flows of a mainline flow with one or two lateral pipeline flows may be estimated by a pressure plus momentum analysis. For example, the City of Los Angeles' Thompson equation relates the pressure plus momentum to the change in HGL by

$$\Delta\mathrm{HGL} = \frac{Q_2V_2 - Q_1V_1\cos(\mathrm{ang1}) - Q_3V_3\cos(\mathrm{ang3}) - Q_4V_4\cos(\mathrm{ang4})}{g(A_1 + A_2)/2} \tag{17}$$

where

Q_1, V_1, A_1 = upstream flow rate, flow velocity, and pipe area
Q_2, V_2, A_2 = downstream flow rate, flow velocity, and pipe area
Q_3, V_3 = lateral flow rate, and flow velocity
Q_4, V_4 = lateral flow rate, and flow velocity
ang1 = angle of confluence between upstream and downstream pipes
ang3, ang4 = angles of confluence between laterals and downstream pipes

Friction losses are computed using equation (8) to estimate the friction slope for both the upstream and downstream reaches. Using the average of the two friction slopes, the friction loss, H_f, is computed based on the length of the junction structure. Should flows enter the junction structure through an inlet constructed at the top of the structure (see Fig. 9), an additional entrance loss may be included and can be estimated as a loss associated to a catch basin inlet, H_{cb}, where

$$H_{cb} = 0.20H_v \tag{18}$$

The junction losses can then be expressed as

$$H_j = \mathrm{HGL} + H_{v1} - H_{v2} + H_{cb} + H_f \tag{19}$$

The above pressure-plus-momentum equation is a crude approximation of the governing integral equation. In the

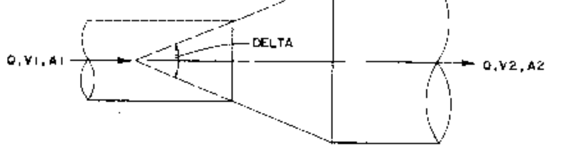


Fig. 8. Transition loss model geometry

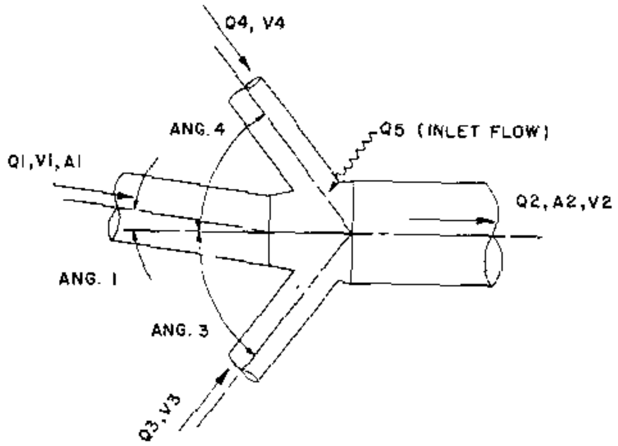


Fig. 9. Junction loss model geometry

computer program, the manhole loss of equation (10) is also computed and used for H_j whenever greater.

Catch basin losses

Inlets into the storm drain system (or catch basins) are often designed in anticipation that both the HGL and EGL coincide with the ponded water surface within the inlet. Consequently, the kinetic energy of flow (or velocity head) and any losses due to the entrance of the flow into the pipeline must be accounted for in the computation of the EGL within the basin. The entrance losses can be estimated as

$$H_{cb} = K_{cb} \cdot H_v \tag{20}$$

where K_{cb} is an entrance-losses coefficient which is experimentally determined. In the program, $K_{cb} = 0.20$.

PROFILE CALCULATION

Nonpressure flow in drainage reach

In nonpressure flow systems the gradually varied flow profiles[1] are generally computed by using any of three popular methods, namely, the graphical-integration method, the direct-integration method, and the standard step method. The standard step method[1] continues to be the most commonly used.

In the standard step method, the computation of the flow depth is carried out on a station basis where the hydraulic characteristics are known. The computation procedure is a trial and error method to balance the energy equation.

For convenience, the position of the water surface is measured with respect to a horizontal datum. The water surface elevations above the datum at the two end sections can be expressed as (Fig. 1b)

$$Z_A = y_A + z_A \tag{21}$$

and

$$Z_B = y_B + z_B \tag{22}$$

The friction losses are estimated between points A and B by

$$h_f = S_f\,dx = (S_A + S_B)\,dx/2 \tag{23}$$

where S_f can be taken as the average of the friction slopes at the two end sections. The total head at sections A and B can be equated by the energy equation

$$S_0\,dx + y_A + \alpha_A V_A^2/2g = y_B + \alpha_B V_B^2/2g + S_f\,dx + h_e \tag{24}$$

By substitution, the following is written

$$Z_A + c_A V_A^2/2g = Z_B + c_B V_B^2/2g + h_f + h_e \tag{25}$$

where h_e is the eddy loss defined by

$$h_e = k(\alpha V^2/2g)$$

where

k = 0 to 0.1 for gradually converging reaches
k = 0 to 0.2 for gradually diverging reaches
k = 0.5 for abrupt expansion and contraction
k = 0 for prismatic and regular channel

The total heads at the two end sections A and B are

$$H_A = Z_A + c_A V_A^2/2g \tag{26}$$

and

$$H_B = Z_B + c_B V_B^2/2g \tag{27}$$

Using equations (26) and (27), equation (25) can be expressed as

$$H_A = H_B + h_f + h_e \tag{28}$$

Given the values of H_A (or H_B), the energy head for H_B (or H_A) is computed by estimating possible flowdepths until the governing energy equations are satisfied.

Pressure flow in drainage reach

In a pressure flow sytem, the calculations proceed upstream. The EGL for the upstream point of the study reach can be estimated by adding the proper head losses to the downstream EGL values. The HGL for the upstream section of the study reach is computed by subtracting the velocity head H_v from the EGL, i.e., HGL = EGL − H_v.

Flow sealed or unsealed in drainage reach

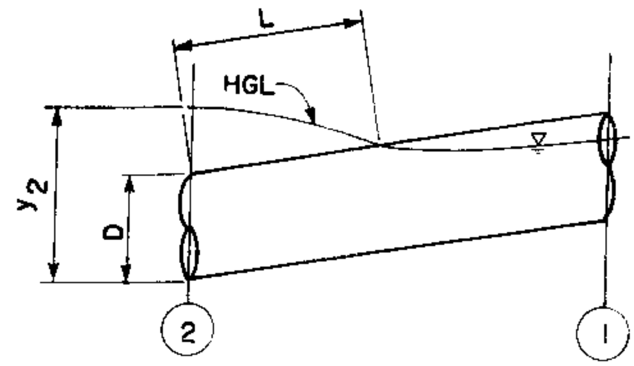
Flow may seal or unseal in any drainage reach. If the design pipe slope is steeper than the hydraulic gradient for the conduit selected, the conduit may unseal. If the design pipe slope is milder than the hydraulic gradient for the conduit selected, the conduit may seal. In both cases, sufficient pipe length must exist in order for flow to seal or unseal at a downstream section. Should flow seal in a drainage reach (Fig. 10a), the length of pipe under pressure can be estimated by

$$L = \frac{y_2 - D}{S_0 - S_f} \tag{29}$$

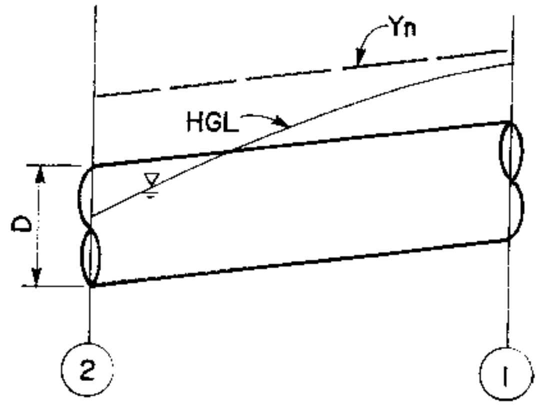
where

y_2 = pressure head at downstream section
D = diameter of pipe
S_0 = designed slope of reach
S_F = friction slope of reach

Should flow unseal in a drainage reach (Fig. 10b), the gradually varied flow profile proceeds until the depth reach the pipe diameter. Thereafter, the pressure flow friction losses is used to estimate the HGL and EGL for the upstream section.



(a) Flow seals in drainage reach



(b) Flow unseals in drainage reach

Fig. 10. Flow seals or unseals in a drainage reach

Hydraulic jump in drainage reach
A hydraulic jump in a drainage reach can occur only when upstream flow is in a supercritical flow regime and the downstream flow is in a subcritical flow regime. Both the upstream and downstream hydraulic analysis should be performed in order to approximate the gradually varied flow profile for this drainage reach.

HGL after head losses
At pipe enlargement or reduction locations, the pipe sizes change. The new water depth (nonpressure flow) or the new pressure head (pressure flow) should be adjusted according to the changes of pipe size. After changing in pipe size, the specific energy can be estimated for the new pipe sizes. Then a new specific energy curve is constructed so that the new water depth or pressure head can be determined with respect to the new specific energy. Notice that the water depth cannot be greater than the critical depth when the flow analysis proceeds downstream, and the water depth or pressure head cannot be less than the critical depth when the flow analysis proceeds upstream. When pipe sizes remain constant, the above procedure should be followed without constructing a new specific energy curve. For head losses which depend upon both upstream and downstream velocity head, or iteration procedure is used to balance the head losses with respect to the upstream and downstream velocity head.

Profile determination
For each drainage reach, the pressure plus momentum values are calculated for both upstream and downstream analyses at downstream and upstream sections. Higher pressure plus momentum values will be used to determine the water surface profile (see Table 4).

Table 4. Logic of profile determination

Pressure plus momentum			
Upstream analysis		Downstream analysis	Flow regime
upstream section	>	upstream section	Subcritical flow
upstream section downstream section	≤ <	upstream section downstream section	Supercritical flow
upstream section downstream section	< ≥	downstream section downstream section	Hydraulic jump

STORM DRAIN COMPUTER MODEL

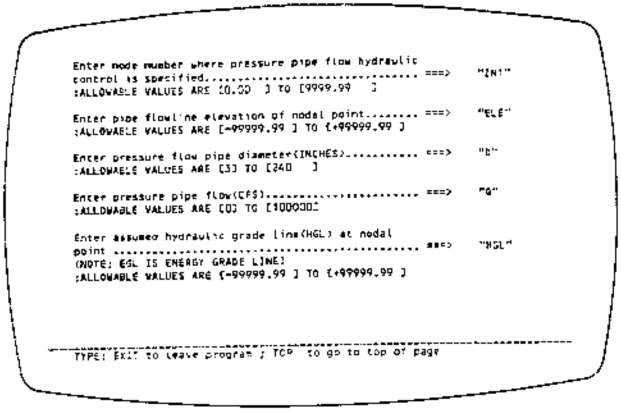
A storm drain computer model based on the storm drain pressure flow model[6] was developed to illustrate the hydraulic analysis procedures. This program employed the user-friendly, form fill-out data technique[2] to increase the user efficiency, and decrease the total cost of engineering design process. The storm drain computer model is composed of a Main Menu program and nine subroutine analysis procedures. The model is developed by linking the Main Menu selection program to each subroutine in order to enable the engineer to branch to the desired analysis procedure when optioned. The various energy loss calculation options are listed in Table 5.

Table 5. Storm drain computer model programs

Program	Description
1	Main menu
2	Friction losses
3	Manhole losses
4	Bend losses
5	Sudden enlargement losses
6	Junction losses
7	Angle point losses
8	Sudden contraction losses
9	Catch basin losses
10	Transition losses

Data entry for various programs are depicted as follows:

PROGRAM 1: DATA ENTRY



```
Enter node number where pressure pipe flow hydraulic
control is specified................................. ===>    "IN1"
:ALLOWABLE VALUES ARE [0.00  ] TO [9999.99   ]

Enter pipe flowline elevation of nodal point........ ===>    "ELE"
:ALLOWABLE VALUES ARE [-99999.99 ] TO [+99999.99 ]

Enter pressure flow pipe diameter(INCHES)........... ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter pressure pipe flow(CFS)....................... ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [100000]

Enter assumed hydraulic grade line(HGL) at nodal
point ............................................... ===>    "HGL"
(NOTE; EGL IS ENERGY GRADE LINE)
:ALLOWABLE VALUES ARE [-99999.99 ] TO [+99999.99 ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
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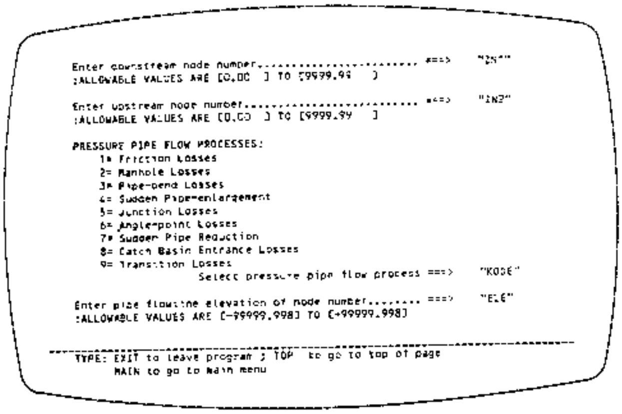

```
Enter downstream node number......................... ===>    "IN1"
:ALLOWABLE VALUES ARE [0.00  ] TO [9999.99   ]

Enter upstream node number........................... ===>    "IN2"
:ALLOWABLE VALUES ARE [0.00  ] TO [9999.99   ]

PRESSURE PIPE FLOW PROCESSES:
    1= Friction Losses
    2= Manhole Losses
    3= Pipe-bend Losses
    4= Sudden Pipe-enlargement
    5= Junction Losses
    6= Angle-point Losses
    7= Sudden Pipe Reduction
    8= Catch Basin Entrance Losses
    9= Transition Losses
                  Select pressure pipe flow process ===>    "KODE"

Enter pipe flowline elevation of node number........ ===>    "ELE"
:ALLOWABLE VALUES ARE [-99999.998] TO [+99999.998]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
         MAIN to go to main menu
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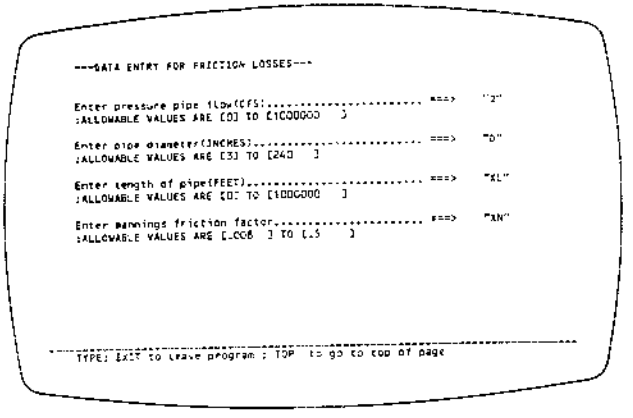
PROGRAM 2: DATA ENTRY



```
---DATA ENTRY FOR FRICTION LOSSES---

Enter pressure pipe flow(CFS)........................ ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter pipe diameter(INCHES).......................... ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter length of pipe(FEET)........................... ===>    "XL"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter mannings friction factor....................... ===>    "XN"
:ALLOWABLE VALUES ARE [.008  ] TO [.5    ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
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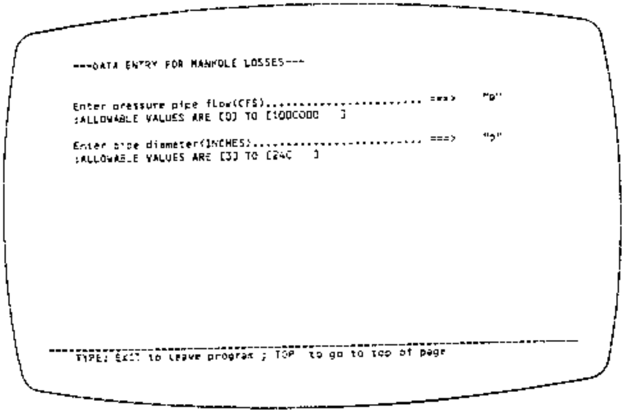
PROGRAM 3: DATA ENTRY



```
---DATA ENTRY FOR MANHOLE LOSSES---

Enter pressure pipe flow(CFS)........................ ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter pipe diameter(INCHES).......................... ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
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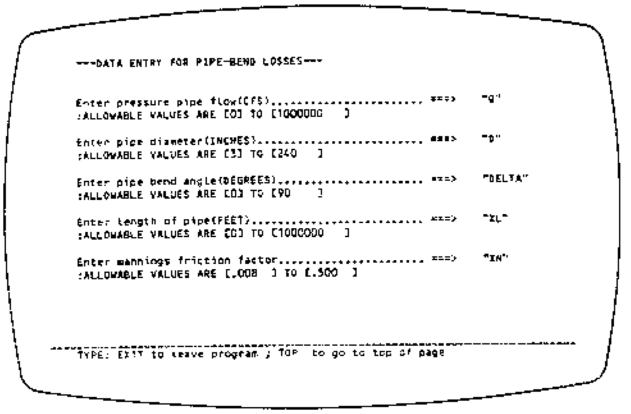
PROGRAM 4: DATA ENTRY



```
---DATA ENTRY FOR PIPE-BEND LOSSES---

Enter pressure pipe flow(CFS)........................ ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter pipe diameter(INCHES).......................... ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

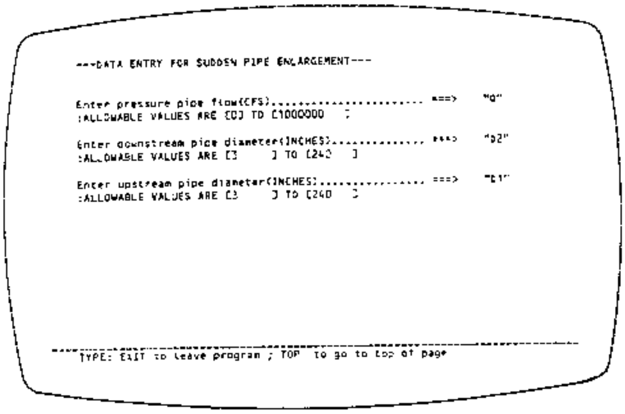
Enter pipe bend angle(DEGREES)....................... ===>    "DELTA"
:ALLOWABLE VALUES ARE [0] TO [90    ]

Enter length of pipe(FEET)........................... ===>    "XL"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter mannings friction factor....................... ===>    "XN"
:ALLOWABLE VALUES ARE [.008  ] TO [.500  ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
```

PROGRAM 5: DATA ENTRY



```
---DATA ENTRY FOR SUDDEN PIPE ENLARGEMENT---

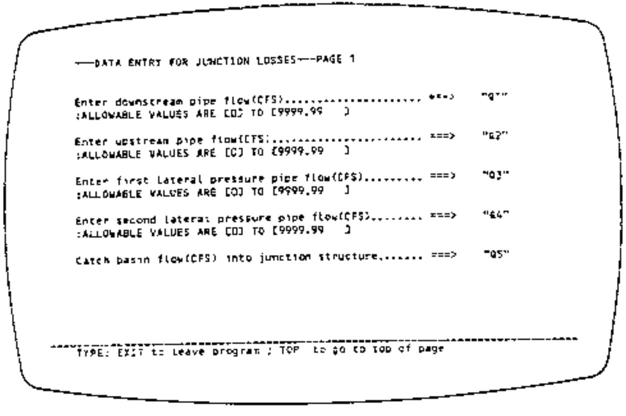
Enter pressure pipe flow(CFS)........................ ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter downstream pipe diameter(INCHES)............... ===>    "D2"
:ALLOWABLE VALUES ARE [3     ] TO [240   ]

Enter upstream pipe diameter(INCHES)................. ===>    "D1"
:ALLOWABLE VALUES ARE [3     ] TO [240   ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
```

PROGRAM 6: DATA ENTRY



```
---DATA ENTRY FOR JUNCTION LOSSES---PAGE 1

Enter downstream pipe flow(CFS)...................... ===>    "Q1"
:ALLOWABLE VALUES ARE [0] TO [9999.99   ]

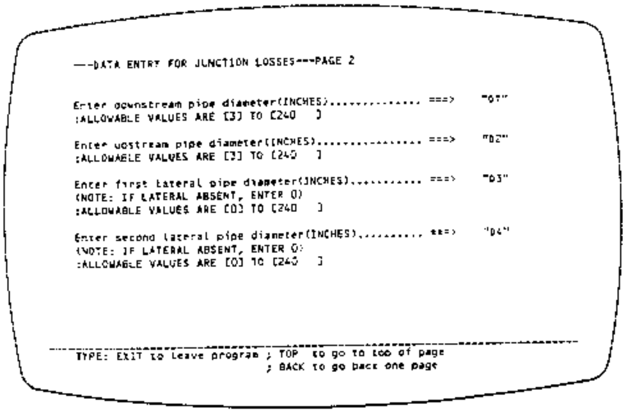
Enter upstream pipe flow(CFS)........................ ===>    "Q2"
:ALLOWABLE VALUES ARE [0] TO [9999.99   ]

Enter first lateral pressure pipe flow(CFS).......... ===>    "Q3"
:ALLOWABLE VALUES ARE [0] TO [9999.99   ]

Enter second lateral pressure pipe flow(CFS)......... ===>    "Q4"
:ALLOWABLE VALUES ARE [0] TO [9999.99   ]

Catch basin flow(CFS) into junction structure....... ===>    "Q5"

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
```



```
---DATA ENTRY FOR JUNCTION LOSSES---PAGE 2

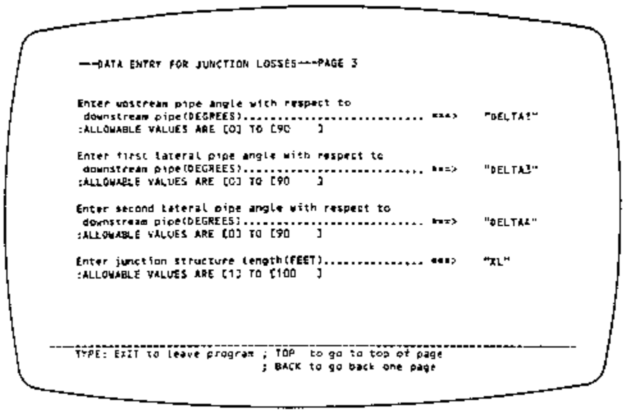
Enter downstream pipe diameter(INCHES)............... ===>    "D1"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter upstream pipe diameter(INCHES)................. ===>    "D2"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter first lateral pipe diameter(INCHES)............ ===>    "D3"
(NOTE: IF LATERAL ABSENT, ENTER 0)
:ALLOWABLE VALUES ARE [0] TO [240   ]

Enter second lateral pipe diameter(INCHES)........... ===>    "D4"
(NOTE: IF LATERAL ABSENT, ENTER 0)
:ALLOWABLE VALUES ARE [0] TO [240   ]

-----------------------------------------------------------------------
   TYPE: EXIT to leave program ; TOP  to go to top of page
                                ; BACK to go back one page
```



```
---DATA ENTRY FOR JUNCTION LOSSES---PAGE 3

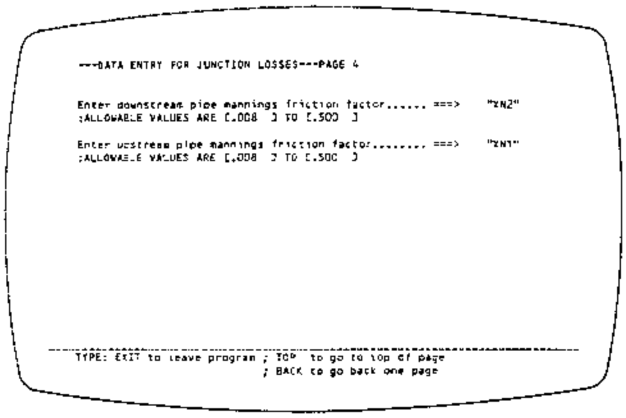
Enter upstream pipe angle with respect to
 downstream pipe(DEGREES).......................... ===>    "DELTA1"
:ALLOWABLE VALUES ARE [0] TO [90    ]

Enter first lateral pipe angle with respect to
 downstream pipe(DEGREES).......................... ===>    "DELTA3"
:ALLOWABLE VALUES ARE [0] TO [90    ]

Enter second lateral pipe angle with respect to
 downstream pipe(DEGREES).......................... ===>    "DELTA4"
:ALLOWABLE VALUES ARE [0] TO [90    ]

Enter junction structure length(FEET).............. ===>    "XL"
:ALLOWABLE VALUES ARE [1] TO [100   ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
                               ; BACK to go back one page
```



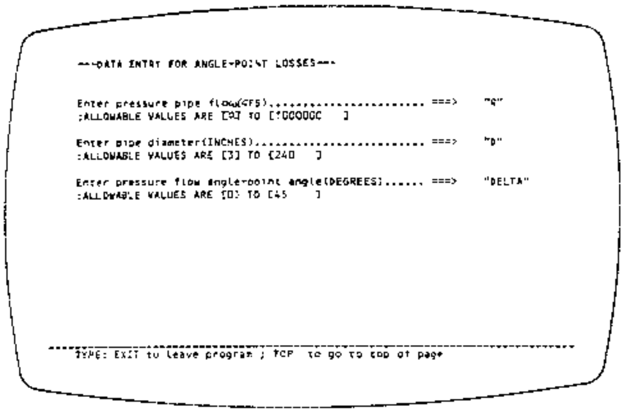
```
---DATA ENTRY FOR JUNCTION LOSSES---PAGE 4

Enter downstream pipe mannings friction factor...... ===>    "XN2"
:ALLOWABLE VALUES ARE [.008  ] TO [.500  ]

Enter upstream pipe mannings friction factor........ ===>    "XN1"
:ALLOWABLE VALUES ARE [.008  ] TO [.500  ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
                               ; BACK to go back one page
```

PROGRAM 7: DATA ENTRY



```
---DATA ENTRY FOR ANGLE-POINT LOSSES---

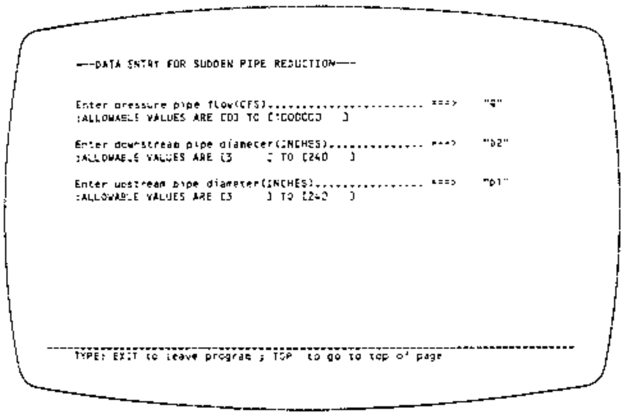
Enter pressure pipe flow(CFS)....................... ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter pipe diameter(INCHES)......................... ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter pressure flow angle-point angle(DEGREES)...... ===>    "DELTA"
:ALLOWABLE VALUES ARE [0] TO [45    ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
```

PROGRAM 8: DATA ENTRY



```
---DATA ENTRY FOR SUDDEN PIPE REDUCTION---

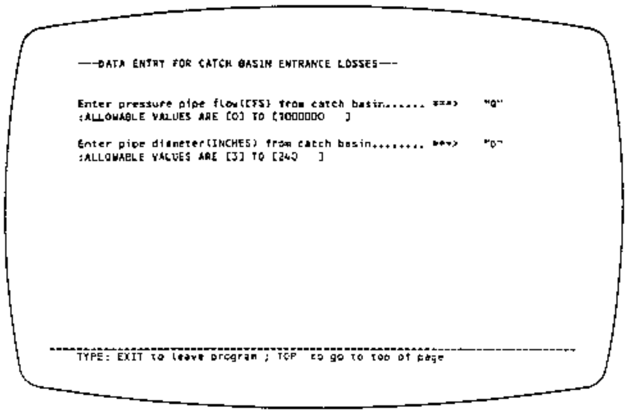
Enter pressure pipe flow(CFS)....................... ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter downstream pipe diameter(INCHES).............. ===>    "D2"
:ALLOWABLE VALUES ARE [3     ] TO [240   ]

Enter upstream pipe diameter(INCHES)................ ===>    "D1"
:ALLOWABLE VALUES ARE [3     ] TO [240   ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
```

PROGRAM 9: DATA ENTRY



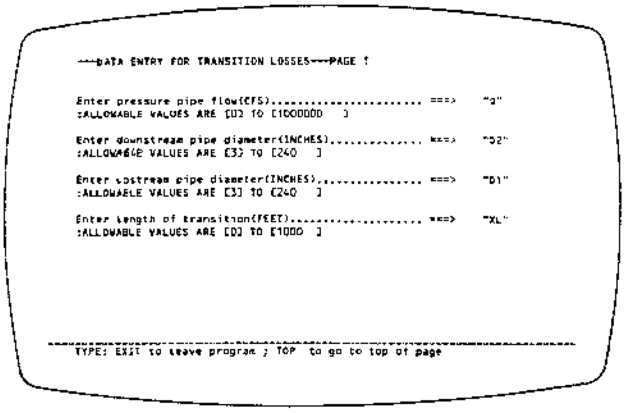
```
---DATA ENTRY FOR CATCH BASIN ENTRANCE LOSSES---

Enter pressure pipe flow(CFS) from catch basin...... ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter pipe diameter(INCHES) from catch basin........ ===>    "D"
:ALLOWABLE VALUES ARE [3] TO [240   ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
```

PROGRAM 10: DATA ENTRY



```
---DATA ENTRY FOR TRANSITION LOSSES---PAGE 1

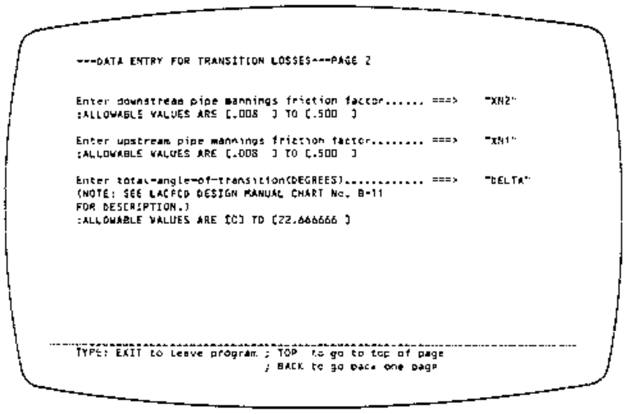
Enter pressure pipe flow(CFS)....................... ===>    "Q"
:ALLOWABLE VALUES ARE [0] TO [1000000   ]

Enter downstream pipe diameter(INCHES).............. ===>    "D2"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter upstream pipe diameter(INCHES)................ ===>    "D1"
:ALLOWABLE VALUES ARE [3] TO [240   ]

Enter length of transition(FEET).................... ===>    "XL"
:ALLOWABLE VALUES ARE [0] TO [1000  ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
```



```
---DATA ENTRY FOR TRANSITION LOSSES---PAGE 2

Enter downstream pipe mannings friction factor...... ===>    "XN2"
:ALLOWABLE VALUES ARE [.008  ] TO [.500  ]

Enter upstream pipe mannings friction factor........ ===>    "XN1"
:ALLOWABLE VALUES ARE [.008  ] TO [.500  ]

Enter total-angle-of-transition(DEGREES)............ ===>    "DELTA"
(NOTE: SEE LACFCD DESIGN MANUAL CHART No. B-11
FOR DESCRIPTION.)
:ALLOWABLE VALUES ARE [0] TO [22.666666 ]

------------------------------------------------------------------------
    TYPE: EXIT to leave program ; TOP  to go to top of page
                               ; BACK to go back one page
```

APPLICATION

An example problem taken from the Highway Design Manual of Instruction (the Los Angeles Road Department) is used to illustrate the capability of the storm drain computer model. The analysed drainage system is depicted on Fig. 11. The downstream hydraulic grade line is assumed to be at elevation 196.70. The upstream sections 14 and 15 are the transition structure and box structure respectively. The box structures were not analysed because of the limitation of the model (circular section only). Therefore, the upstream control depth was assumed to be the normal depth (1.61 ft) of that reach. In the reach between sections 12 and 14, the water surface was defaulted to normal depth due to the steep slope. A flow depth of 1.84 ft was estimated after flow

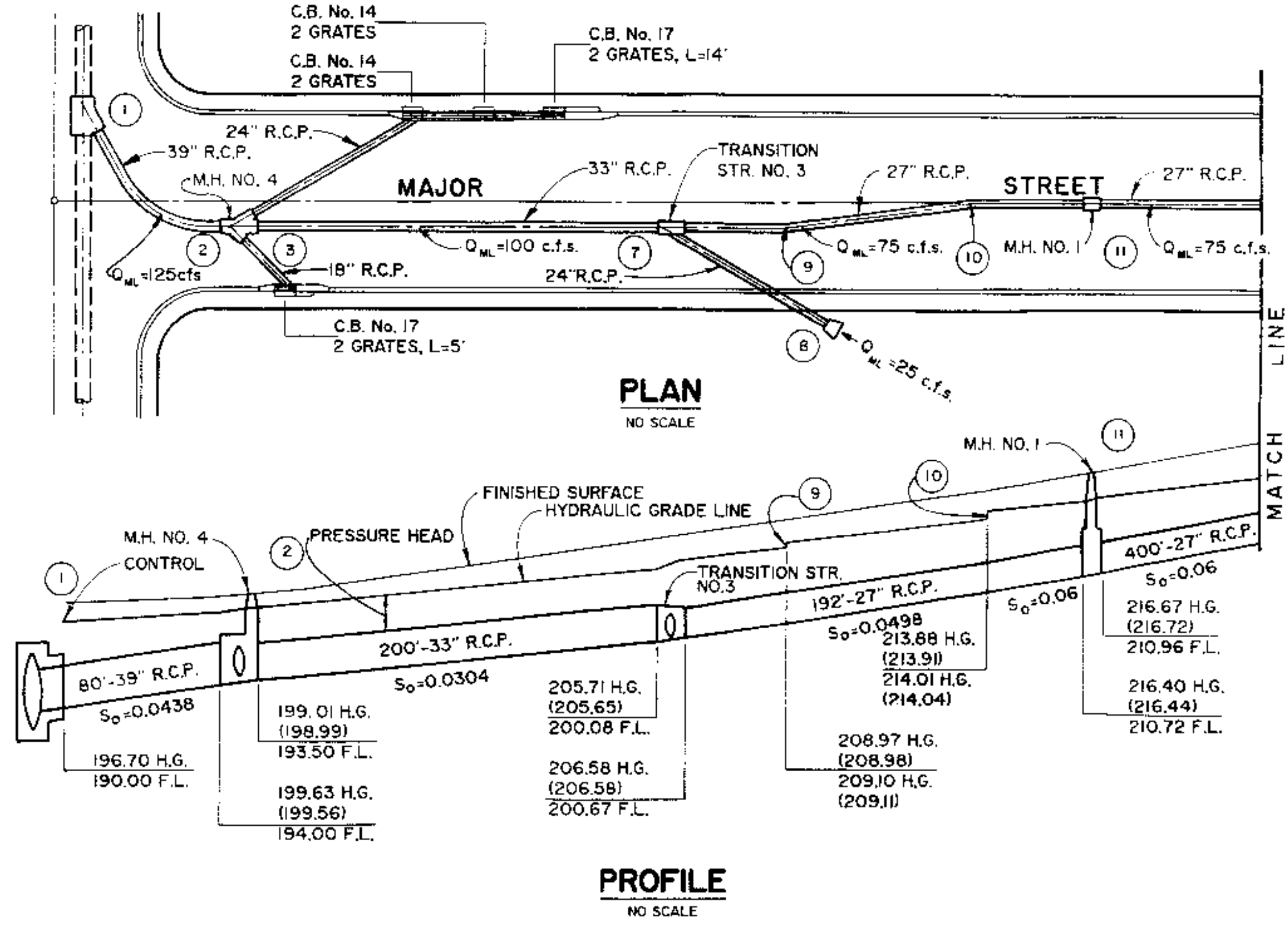


Fig. 11. Hydraulics example

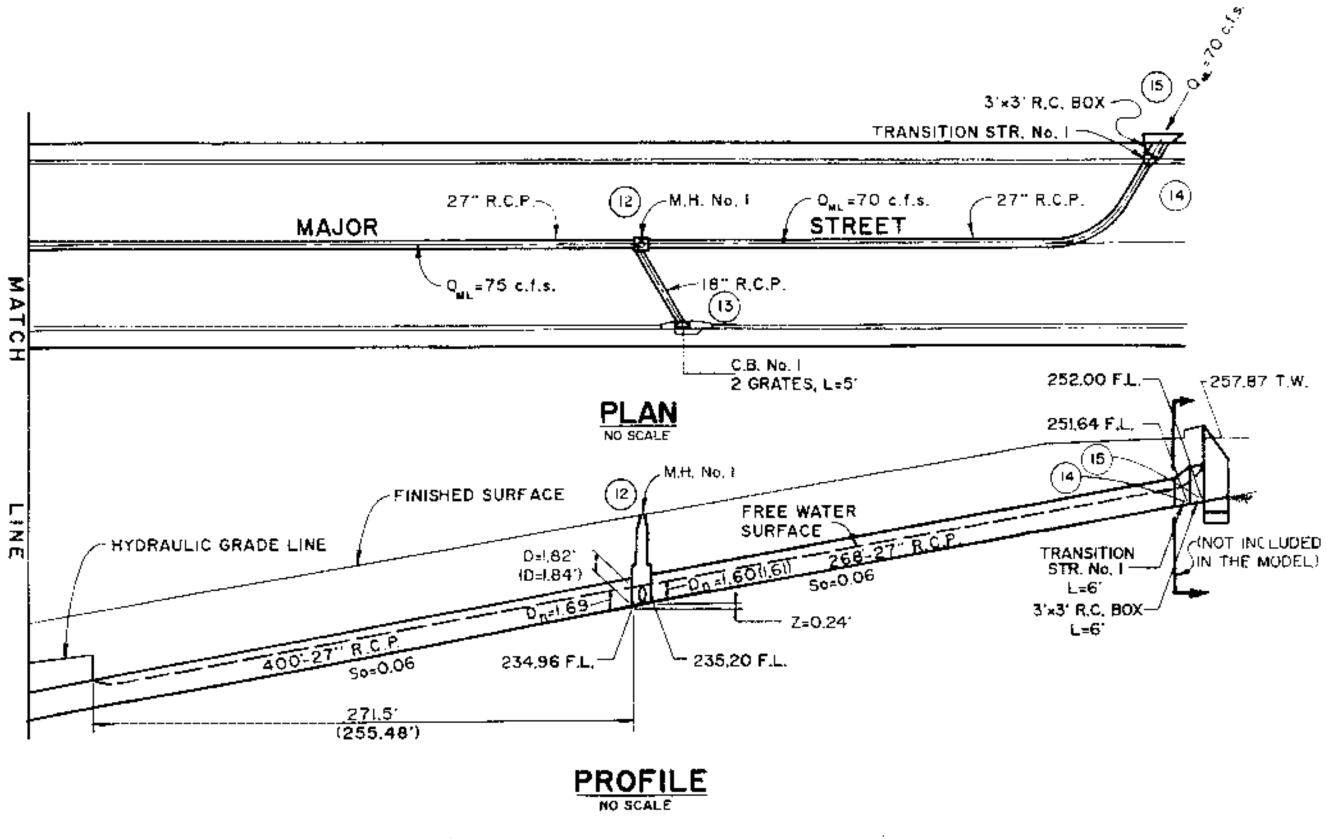


Fig. 11. Hydraulics example (continued)

passing through a manhole structure at section 12. A hydraulic jump was predicted by the storm drain computer model and the location of the pressure plus momentum balance occurred about 255.48 ft from section 12. A gradually varied flow profile was also calculated by the model for this nonpressure segment. The example calculated in the manual used the normal depth (1.69 ft) for the nonpressure flow segment. The normal depth provided less pressure plus momentum forces to push the flow downstream (271.5 ft) as model predicted (322.8 ft). Pressure system calculations were well-predicted by the model when compared to the manual results from section 11 to section 1.

Computer model results are included in the Appendix. First the nodal point status table which contains the flow depth, pressure head and pressure plus momentum for upstream and downstream analyses is printed for user's convenience. The section (node) numbers are arranged from upstream to downstream. User specified head loss options are also printed. 'Hydraulic jump' will be printed when it occurred in the pipe reach. Control pressure head on flow depth of each section is followed by an asterisk for user's convenience. Entire hydraulic analysis is also included after the nodal point status table. Head losses calculations, HGL, EGL and flow line are printed for each section. Only one gradually varied flow profile will be selected with respect to the control flow depth. In a reach where hydraulic jump occurs, both supercritical and subcritical flow profiles are printed. However, the determination of the location and length of hydraulic jumps is not included in the programming. Rather, this type of information is currently indeterminate and is left to the engineer for special consideration on a case by case basis. A common approach is to assume the jump to occur as a shock whereby the conjugate depths are matched at a single point, with the length of the jump being assumed as zero. The type of solution may be unacceptable in cases where a pipe lateral enters the main channel immediately upstream of such an assumed hydraulic jump shock, and the hydraulic control for the pipeline is assumed to be the lower conjugate depth.

DISCUSSIONS

The storm drain computer model has the capability to analyse a general storm drain pipe system. Furthermore, it can analyse hydraulic jumps, pressure and nonpressure flow in any drainage reach. Gradually varied flow profiles are approximated by the standard step method when nonpressure flow occurs in any pipe reach. This analysis provided the hydraulic engineer a better understanding of the storm drain system hydraulics when pressure and nonpressure flow co-exist in the storm drain system.

Because the computer program is interactive, the pipe system can be quickly designed without the use of a data batch-file approach.

REFERENCES

1 Chow, V. T. Open Channel Hydraulics, McGraw-Hill Company, 1959

2 Clements, J. M. and Hromadka II, T. V. User-Friendly, Form Fill-out Data for Engineering Software, *Microsoftware for Engineers*, 1986, **2**(1), 1320

3 Design Manual: Channel Hydraulics and Structures, Orange County Flood District, OCEMA, California, 1972

4 Design Manual: Hydraulic, Los Angeles County Flood Control District, Los Angeles, California, 1970

5 Design Manual: Los Angeles County Road Department, Los Angeles, California, 1972

6 Hromadka II, T. V., Clements, J. M. and Saluja, H. Computer Method in Urban Watershed Hydraulics, Lighthouse Publications, Mission Viejo, California, 1984

APPENDIX: EXAMPLE RESULTS

```
**************************************************************************
--------------------------------------------------------------------------
**************************************************************************
               GRADUALLY VARIED FLOW ANALYSIS FOR PIPE SYSTEM
                         NODAL POINT STATUS TABLE
                 (Note: "*" indicates nodal point data used.)
                      UPSTREAM RUN                     DOWNSTREAM RUN
  NODE    MODEL   PRESSURE     PRESSURE+          FLOW         PRESSURE+
 NUMBER  PROCESS  HEAD(FT)  MOMENTUM(POUNDS)    DEPTH(FT)  MOMENTUM(POUNDS)
  14.00-             2.23          2665.75        1.61*          3254.63
      | FRICTION
  12.00-             3.56          2991.17        1.61*          3254.67
      | JUNCTION
  12.00-             2.24          3019.46        1.84*          3316.98
      | FRICTION         | HYDRAULIC JUMP
  11.00-             5.76*         3890.39        1.69           3545.29
      | MANHOLE
  11.00-             5.72*         3881.40        1.71           3509.36
      | FRICTION
  10.00-             6.20*         4000.86        1.71           3525.57
      | ANGLE-POINT
  10.00-             6.07*         3967.96        1.71           3525.57
      | FRICTION
   9.00-             6.05*         3963.72        1.78           3406.41
      | ANGLE-POINT
   9.00-             5.92*         3930.82        1.78           3406.41
      | FRICTION
   7.00-             5.91*         3928.70        1.80           3373.73
      | JUNCTION
   7.00-             5.57*         4818.52        2.39           3913.90
      | FRICTION
   2.00-             5.56*         4813.80        2.29           4014.39
      | JUNCTION
   2.00-             5.49*         5649.63        2.93           4522.51
      | FRICTION+BEND
   1.00-             6.70*         6277.10        2.29           5247.53
--------------------------------------------------------------------------
 MAXIMUM NUMBER OF ENERGY BALANCES USED IN EACH PROFILE =  25
--------------------------------------------------------------------------
 NOTE: STEADY FLOW HYDRAULIC HEAD-LOSS COMPUTATIONS BASED ON THE MOST
 CONSERVATIVE FORMULAE FROM THE CURRENT LACRD,LACFCD, AND OCEMA
 DESIGN MANUALS.
**************************************************************************
 UPSTREAM PIPE FLOW CONTROL DATA:
 NODE NUMBER =     14.00                FLOWLINE ELEVATION =   251.28
 ASSUMED UPSTREAM CONTROL HGL =    252.89
--------------------------------------------------------------------------
 NODE    14.00 : HGL = <  252.890>;EGL= <  261.099>;FLOWLINE= <  251.280>

**************************************************************************
 FLOW PROCESS FROM NODE    14.00 TO NODE    12.00 IS CODE =  1
 UPSTREAM NODE    14.00     ELEVATION =   251.28  (FLOW IS SUPERCRITICAL)
--------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW    =      70.00 CFS           PIPE DIAMETER =  27.00 INCHES
 PIPE LENGTH =     274.00 FEET           MANNING'S N  =   .01200
--------------------------------------------------------------------------
 NORMAL DEPTH(FT) =      1.61            CRITICAL DEPTH(FT) =       2.23
==========================================================================
 UPSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =     1.61
==========================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
--------------------------------------------------------------------------
 DISTANCE FROM        PRESSURE   VELOCITY      SPECIFIC        PRESSURE+
  CONTROL(FT)         HEAD(FT)   (FT/SEC)     ENERGY(FT)   MOMENTUM(POUNDS)
          .000          1.610     22.985          9.819          3254.63
       274.000          1.610     22.986          9.819          3254.67
--------------------------------------------------------------------------
 NODE    12.00 : HGL = <  236.810>;EGL= <  245.019>;FLOWLINE= <  235.200>

**************************************************************************
 FLOW PROCESS FROM NODE    12.00 TO NODE    12.00 IS CODE =  5
 UPSTREAM NODE    12.00     ELEVATION =   235.20  (FLOW IS SUPERCRITICAL)
--------------------------------------------------------------------------
 CALCULATE JUNCTION LOSSES:
      PIPE        FLOW       DIAMETER    ANGLE       CRITICAL
                  (CFS)      (INCHES)   (DEGREES)    DEPTH(FT.)
    UPSTREAM      70.00       27.00         .00          2.23
   DOWNSTREAM     75.00       27.00         -            2.24
   LATERAL #1      5.00       18.00       60.00           .86
   LATERAL #2       .00         .00         .00           .00
      Q5            .00===Q5 EQUALS BASIN INPUT===

 LACFCD AND OCEMA FLOW JUNCTION FORMULAE USED:
 DY=(Q2*V2-Q1*V1*COS(DELTA1)-Q3*V3*COS(DELTA3)-
     Q4*V4*COS(DELTA4))/((A1+A2)*16.1)
 MANNING'S N: UPSTREAM =  .01200;                DOWNSTREAM =  .01200
 JUNCTION LENGTH =   4.00 FEET                   FRICTION LOSS =  .21793 FEET
 ENTRANCE LOSSES =   .000 FEET
 JUNCTION LOSSES = (DY+HV1-HV2)+(FRICTION LOSS)+(ENTRANCE LOSSES)
 JUNCTION LOSSES = (  .779)+(  .218)+(  .000) =    .997
--------------------------------------------------------------------------
 NODE    12.00 : HGL = <  236.798>;EGL= <  244.022>;FLOWLINE= <  234.960>
**************************************************************************
 FLOW PROCESS FROM NODE    12.00 TO NODE    11.00 IS CODE =  1
 UPSTREAM NODE    12.00     ELEVATION =   234.96  (HYDRAULIC JUMP OCCURS)
--------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW           75.00 CFS          PIPE DIAMETER =  27.00 INCHES
 PIPE LENGTH =     400.00 FEET          MANNING'S N  =   .01200
```

```
------------------------------------------------------------------------
 HYDRAULIC JUMP: DOWNSTREAM RUN ANALYSIS RESULTS
------------------------------------------------------------------------
 NORMAL DEPTH(FT) =      1.69            CRITICAL DEPTH(FT) =      2.24
========================================================================
 UPSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =      1.84
========================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
------------------------------------------------------------------------
 DISTANCE FROM       FLOW DEPTH  VELOCITY     SPECIFIC       PRESSURE+
  CONTROL(FT)            (FT)    (FT/SEC)    ENERGY(FT)   MOMENTUM(POUNDS)
         .000           1.836     21.563         9.062         3316.98
        3.921           1.832     21.627         9.099         3325.17
        8.039           1.826     21.693         9.138         3333.36
       12.371           1.620     21.759         9.176         3341.72
       16.939           1.814     21.826         9.216         3350.20
       21.765           1.808     21.894         9.256         3358.79
       26.874           1.802     21.963         9.297         3367.50
       32.299           1.796     22.032         9.338         3376.33
       38.075           1.790     22.103         9.381         3385.27
       44.244           1.784     22.173         9.423         3394.33
       50.857           1.778     22.245         9.467         3403.52
       57.977           1.772     22.318         9.511         3412.82
       65.677           1.766     22.391         9.556         3422.25
       74.051           1.760     22.466         9.602         3431.80
       83.017           1.754     22.541         9.649         3441.48
       93.115           1.748     22.617         9.696         3451.27
      104.575           1.742     22.695         9.744         3461.20
      117.236           1.736     22.773         9.793         3471.25
      131.687           1.730     22.849         9.843         3481.43
      148.456           1.724     22.929         9.893         3491.74
      168.474           1.719     23.009         9.944         3502.19
      193.100           1.713     23.090         9.996         3512.76
      225.077           1.707     23.172        10.049         3523.47
      270.431           1.701     23.255        10.103         3534.31
      348.633           1.695     23.339        10.158         3545.28
      400.000           1.695     23.339        10.158         3545.29
------------------------------------------------------------------------
 HYDRAULIC JUMP: UPSTREAM RUN ANALYSIS RESULTS
========================================================================
 DOWNSTREAM CONTROL ASSUMED PRESSURE HEAD(FT) =      5.76
========================================================================
 PRESSURE FLOW PROFILE COMPUTED INFORMATION:
------------------------------------------------------------------------
 DISTANCE FROM       PRESSURE    VELOCITY     SPECIFIC       PRESSURE+
  CONTROL(FT)         HEAD(FT)   (FT/SEC)    ENERGY(FT)   MOMENTUM(POUNDS)
         .000           5.755     18.863        11.280         3890.39
      349.482           2.250     18.863         7.775         3020.67
========================================================================
 ASSUMED DOWNSTREAM PRESSURE HEAD(FT) =      2.25
========================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
------------------------------------------------------------------------
 DISTANCE FROM       FLOW DEPTH  VELOCITY     SPECIFIC       PRESSURE+
  CONTROL(FT)            (FT)    (FT/SEC)    ENERGY(FT)   MOMENTUM(POUNDS)
      349.482           2.250     18.857         7.775         3020.67
      400.000           2.236     18.873         7.770         3019.42
--------------------------END OF HYDRAULIC JUMP ANALYSIS------------------------
! * NOTE: PRESSURE + MOMENTUM BALANCE OCCURS   144.52 FEET FROM NODE   11.00 !
------------------------------------------------------------------------
 NODE    11.00 : HGL = <  216.715>;EGL= <  222.240>;FLOWLINE= <  210.960>

************************************************************************
 FLOW PROCESS FROM NODE     11.00 TO NODE     11.00 IS CODE =  2
 UPSTREAM NODE    11.00      ELEVATION =   210.96  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE MANHOLE LOSSES(LACFCD):
 PIPE FLOW =        75.00 CFS             PIPE DIAMETER =  27.00 INCHES
 FLOW VELOCITY =  18.86 FEET/SEC.         VELOCITY HEAD =  5.525 FEET
 HMN = .05*(VELOCITY HEAD) = .05*( 5.525) =    .276
------------------------------------------------------------------------
 NODE    11.00 : HGL = <  216.439>;EGL= <  221.964>;FLOWLINE= <  210.720>

************************************************************************
 FLOW PROCESS FROM NODE     11.00 TO NODE     10.00 IS CODE =  1
 UPSTREAM NODE    11.00      ELEVATION =   210.72  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW   =       75.00 CFS            PIPE DIAMETER =  27.00 INCHES
 PIPE LENGTH =       48.00 FEET           MANNING'S N  =   .01200
 SF=(Q/K)**2 = ((      75.00)/(   335.512))**2 =  .04997
 HF=L*SF = (     48.00)*( .04997) =       2.399
------------------------------------------------------------------------
 NODE    10.00 : HGL = <  214.041>;EGL= <  219.566>;FLOWLINE= <  207.840>

************************************************************************
 FLOW PROCESS FROM NODE     10.00 TO NODE     10.00 IS CODE =  6
 UPSTREAM NODE    10.00      ELEVATION =   207.84  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE ANGLE-POINT LOSSES(LACRD):
 PIPE FLOW =        75.00 CFS             PIPE DIAMETER =  27.00 INCHES
 PIPE ANGLE-POINT =    8.00 DEGREES       ANGLE-POINT COEFFICIENT KA =  .02400
 FLOW VELOCITY =  18.86 FEET/SEC.            VELOCITY HEAD =  5.525 FEET
 HAPT=KA*(VELOCITY HEAD) = ( .02400)*( 5.525) =    .133
------------------------------------------------------------------------
 NODE    10.00 : HGL = <  213.908>;EGL= <  219.433>;FLOWLINE= <  207.840>
************************************************************************
 FLOW PROCESS FROM NODE     10.00 TO NODE      9.00 IS CODE =  1
 UPSTREAM NODE    10.00      ELEVATION =   207.84  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW   =       75.00 CFS            PIPE DIAMETER =  27.00 INCHES
 PIPE LENGTH =       96.00 FEET           MANNING'S N  =   .01200
 SF=(Q/K)**2 = ((      75.00)/(   335.512))**2 =  .04997
 HF=L*SF = (     96.00)*( .04997) =       4.797
------------------------------------------------------------------------
 NODE     9.00 : HGL = <  209.111>;EGL= <  214.636>;FLOWLINE= <  203.060>
```

```
************************************************************************
 FLOW PROCESS FROM NODE      9.00 TO NODE      9.00 IS CODE =  6
 UPSTREAM NODE     9.00      ELEVATION =   203.06  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE ANGLE-POINT LOSSES(LACRD):
 PIPE FLOW =        75.00 CFS             PIPE DIAMETER =  27.00 INCHES
 PIPE ANGLE-POINT =    8.00 DEGREES       ANGLE-POINT COEFFICIENT KA =  .02400
 FLOW VELOCITY =  18.86 FEET/SEC.            VELOCITY HEAD =  5.525 FEET
 HAPT=KA*(VELOCITY HEAD) = ( .02400)*( 5.525) =    .133
------------------------------------------------------------------------
 NODE     9.00 : HGL = <  208.978>;EGL= <  214.503>;FLOWLINE= <  203.060>

************************************************************************
 FLOW PROCESS FROM NODE      9.00 TO NODE      7.00 IS CODE =  1
 UPSTREAM NODE     9.00      ELEVATION =   203.06  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW   =       75.00 CFS            PIPE DIAMETER =  27.00 INCHES
 PIPE LENGTH =       48.00 FEET           MANNING'S N  =   .01200
 SF=(Q/K)**2 = ((      75.00)/(   335.512))**2 =  .04997
 HF=L*SF = (     48.00)*( .04997) =       2.399
------------------------------------------------------------------------
 NODE     7.00 : HGL = <  206.580>;EGL= <  212.105>;FLOWLINE= <  200.670>

************************************************************************
 FLOW PROCESS FROM NODE      7.00 TO NODE      7.00 IS CODE =  5
 UPSTREAM NODE     7.00      ELEVATION =   200.67  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE JUNCTION LOSSES:
      PIPE         FLOW      DIAMETER    ANGLE      CRITICAL
                   (CFS)     (INCHES)  (DEGREES)    DEPTH(FT.)
    UPSTREAM       75.00       27.00        .00        2.24
   DOWNSTREAM     100.00       33.00         -         2.71
   LATERAL #1      25.00       24.00      30.00        1.76
   LATERAL #2        .00         .00        .00         .00
      Q5             .00===Q5 EQUALS BASIN INPUT===

 LACFCD AND OCEMA FLOW JUNCTION FORMULAE USED:
 DY=(Q2*V2-Q1*V1*COS(DELTA1)-Q3*V3*COS(DELTA3)-
     Q4*V4*COS(DELTA4))/((A1+A2)*16.1)
 MANNING'S N: UPSTREAM =  .01200;                DOWNSTREAM =  .01200
 JUNCTION LENGTH =   8.00 FEET                   FRICTION LOSS =  .32172 FEET
 ENTRANCE LOSSES =   .000 FEET
 JUNCTION LOSSES = (DY+HV1-HV2)+(FRICTION LOSS)+(ENTRANCE LOSSES)
 JUNCTION LOSSES = ( 1.729)+(  .322)+(  .000) =   2.050
------------------------------------------------------------------------
 NODE     7.00 : HGL = <  205.653>;EGL= <  210.054>;FLOWLINE= <  200.080>

************************************************************************
 FLOW PROCESS FROM NODE      7.00 TO NODE      2.00 IS CODE =  1
 UPSTREAM NODE     7.00      ELEVATION =   200.08  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 PIPE FLOW   =      100.00 CFS            PIPE DIAMETER =  33.00 INCHES
 PIPE LENGTH =      200.00 FEET           MANNING'S N  =   .01200
 SF=(Q/K)**2 = ((     100.00)/(   572.940))**2 =  .03046
 HF=L*SF = (    200.00)*( .03046) =       6.093
------------------------------------------------------------------------
 NODE     2.00 : HGL = <  199.560>;EGL= <  203.962>;FLOWLINE= <  194.000>

************************************************************************
 FLOW PROCESS FROM NODE      2.00 TO NODE      2.00 IS CODE =  5
 UPSTREAM NODE     2.00      ELEVATION =   194.00  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE JUNCTION LOSSES:
      PIPE         FLOW      DIAMETER    ANGLE      CRITICAL
                   (CFS)     (INCHES)  (DEGREES)    DEPTH(FT.)
    UPSTREAM      100.00       33.00        .00        2.71
   DOWNSTREAM     125.00       39.00         -         3.15
   LATERAL #1      20.00       24.00      30.00        1.61
   LATERAL #2       5.00       18.00      45.00         .86
      Q5             .00===Q5 EQUALS BASIN INPUT===

 LACFCD AND OCEMA FLOW JUNCTION FORMULAE USED:
 DY=(Q2*V2-Q1*V1*COS(DELTA1)-Q3*V3*COS(DELTA3)-
     Q4*V4*COS(DELTA4))/((A1+A2)*16.1)
 MANNING'S N: UPSTREAM =  .01200;                DOWNSTREAM =  .01200
 JUNCTION LENGTH =   9.00 FEET                   FRICTION LOSS =  .22495 FEET
 ENTRANCE LOSSES =   .000 FEET
 JUNCTION LOSSES = (DY+HV1-HV2)+(FRICTION LOSS)+(ENTRANCE LOSSES)
 JUNCTION LOSSES = ( 1.223)+(  .225)+(  .000) =   1.448
------------------------------------------------------------------------
 NODE     2.00 : HGL = <  198.988>;EGL= <  202.513>;FLOWLINE= <  193.500>

************************************************************************
 FLOW PROCESS FROM NODE      2.00 TO NODE      1.00 IS CODE =  3
 UPSTREAM NODE     2.00      ELEVATION =   193.50  (FLOW IS UNDER PRESSURE)
------------------------------------------------------------------------
 CALCULATE PIPE-BEND LOSSES(OCEMA):
 PIPE FLOW =       125.00 CFS             PIPE DIAMETER =  39.00 INCHES
 CENTRAL ANGLE = 61.000 DEGREES           MANNING'S N =  .01200
 PIPE LENGTH =       80.00 FEET           BEND COEFFICIENT(KB) =  .20582
 FLOW VELOCITY =  15.07 FEET/SEC.         VELOCITY HEAD =  3.525 FEET
 HB=KB*(VELOCITY HEAD) = (  .206)*( 3.525) =    .726
 SF=(Q/K)**2 = ((     125.00)/(   894.495))**2 =  .01953
 HF=L*SF = (     80.00)*( .01953) =  1.562
 TOTAL HEAD LOSSES = HB + HF = (  .726)+( 1.562) =  2.288
------------------------------------------------------------------------
 NODE     1.00 : HGL = <  196.700>;EGL= <  200.225>;FLOWLINE= <  190.000>
************************************************************************
 DOWNSTREAM PIPE FLOW CONTROL DATA:
 NODE NUMBER =      1.00              FLOWLINE ELEVATION =   190.00
 PIPE FLOW =      125.00 CFS          PIPE DIAMETER =  39.00 INCHES
 ASSUMED DOWNSTREAM CONTROL HGL =   196.700
========================================================================
 END OF GRADUALLY VARIED FLOW ANALYSIS
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