Hydraulic analysis for box culvert systems

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INTRODUCTION

A typical storm drain system may consist of pipe systems in the upstream drainage reaches and box culvert systems in the downstream drainage reaches. An interactive computer program in designing storm drain pipe systems has been developed by Yen and Hromadka[5]. Implementation of the hydraulic analysis procedures to a box culvert system follows the same analog as the pipe systems. 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 energy grade line (EGL) and hydraulic grade line (HGL) for the entire storm drain system. Pressure flow, nonpressure flow, hydraulic jumps, and minor losses in each drainage reach can be determined individually.

IMPLEMENTATIONS

The minor loss models, such as friction losses, manhole losses, sudden reduction/enlargement losses, transition losses and junction losses, can be easily implemented to the box system because all the minor loss models are functions of velocity heads.

A gradually varied flow model (Hromadka *et al.*[4]) for rectangular channel sections has been modified to analyze both pressure and non-pressure flow conditions for the box system. Water surface profile determination logic remains the same as the pipe system model (Yen and Hromadka[5]).

Finally, the output formats have been changed to accommodate the box culvert systems (see Appendix).

APPLICATION

An example problem was taken from Los Angeles Flood Control District (LAFCD) (Design Manual: Hydraulic) to illustrate the capability of the box systems model. Figure 1 depicts the plan and profile for the example problem. Table 1 compares the model estimated HGL and EGL to the LAFCD Manual's results. The pressure plus momentum balancing point was estimated at station 2+18 and station 2+10 by the model and LAFCD Manual, respectively. At junction structure (section 4), the computer model defaulted junction losses to the manhole losses. Thus, a higher EGL was estimated by the model, i.e. 72.10 feet by the model and 72.07 feet by the LAFDC Manual. The model estimated gradually varied flow profiles were lower than the LAFCD Manual's estimated profiles. This is mainly because 25 energy balance locations (see Appendix) have been used in the model which resulted in more accurate water surface profiles.

Table 1. HGL and EGL for example problem

Section No.		Hydraulic Grade Line		Energy Grade Line	
		LAFCD Manual	Model estimated	LAFCD Manual	Model estimated
1		66.55	66.55	68.28	68.28
2		64.30	64.29	69.80	69.74
3		69.13	69.12	71.78	71.77
4	Junction Structure	69.82	69.58	71.99	71.98
		70.22	70.29	72.07	72.10
5		72.04	71.99	73.75	73.74
6		71.99	71.86	73.81	73.81
7		72.81	72.59	74.38	74.23
8		73.47	73.21	75.04	74.74
9		73.72	73.51	75.29	75.04

DISCUSSIONS

The box culvert model can analyze the hydraulic jumps, pressure and non-pressure flow conditions in any drainage reach. This program provides the hydraulic engineer a better tool of designing box storm drain systems when pressure and non-pressure flow co-exist in the system. Further analyses on the junction and transition structures are needed in order to integrate the pipe and box culvert models into a general storm drain analysis model.

REFERENCES

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

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

3 Design Manual, Los Angeles County Road Department, Los Angeles, California, 1972

4 Hromadka II, T. V., Beech, B. L. and Clements, J. M. Computational Hydraulics for Civil Engineers. Lighthouse Publication, Mission Viejo, California, 1988

5 Yen, C. C. and Hromadka II, T.V. Interactive hydraulic analysis for storm drain pipe systems. *Hydrosoft*, 1988, 1(4)

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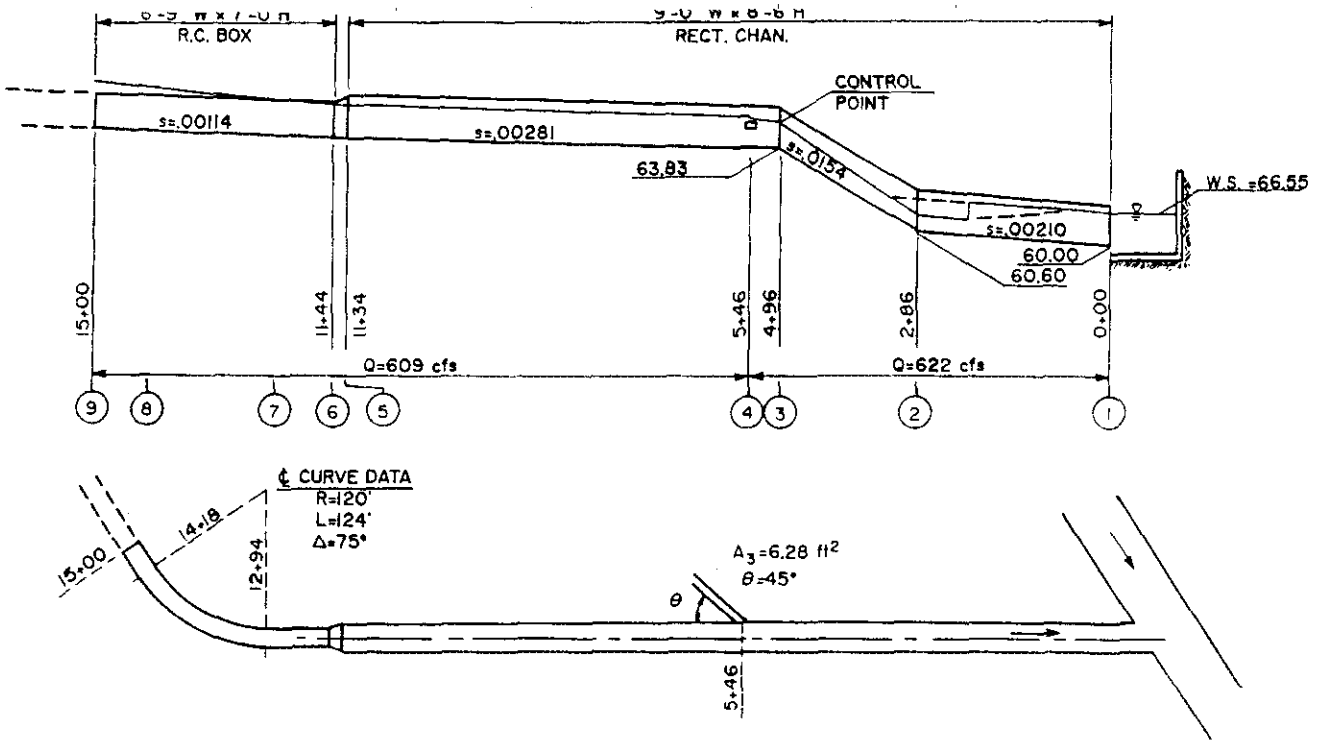

Fig. 1. Plan and profile for example problem

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FILE NAME: LBOX1.DAT
TIME/DATE OF STUDY: 16: 0   6/28/1989

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                GRADUALLY VARIED FLOW ANALYSIS FOR BOX 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)
  9.00-                7.46*        26888.19       5.32 Dc        23166.42
     } FRICTION
  8.00-                7.26*        26099.09       5.32 Dc        23166.42
     } FRICTION+BEND
  7.00-                6.78*        24659.67       5.32 Dc        23166.42
     } FRICTION
  6.00-                6.22*        23771.27       5.32 Dc        23166.42
     } TRANSITION
  5.00-                6.38*        23945.73       4.70           23193.86
     } FRICTION
  4.00-                6.27*        23780.55       5.22 Dc        22949.90
     } JUNCTION
  4.00-                5.57*        23666.96       5.29 Dc        23605.41
     } FRICTION
  3.00-             5.29 Dc         23605.41       5.29*Dc        23605.41
     } FRICTION
  2.00-                6.80         25233.02       3.69*          26399.63
     } FRICTION          } HYDRAULIC JUMP
  1.00-                6.55*        24765.23       5.29 Dc        23605.41

MAXIMUM NUMBER OF ENERGY BALANCES USED IN EACH PROFILE =  25
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NOTE: STEADY FLOW HYDRAULIC HEAD-LOSS COMPUTATIONS BASED ON THE MOST
CONSERVATIVE FORMULAE FROM THE CURRENT LACRD,LACFCD, AND OCEMA
DESIGN MANUALS.
--------------------------------------------------------------------------------
 NODE     9.00 : HGL = <   73.505>;EGL= <   75.040>;FLOWLINE= <   66.040>
********************************************************************************
 FLOW PROCESS FROM NODE      9.00 TO NODE      8.00 IS CODE =  1
 UPSTREAM NODE      9.00     ELEVATION =    66.04  (FLOW IS UNDER PRESSURE)
--------------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 BOX FLOW    =      609.00 CFS
 BOX BASEWIDTH =    8.75 FEET          BOX HEIGHT =    7.00 FEET
 BOX LENGTH =       82.00 FEET         MANNING'S N  =   .01400
 SF=(Q/K)**2 = ((     609.00)/( 10128.360))**2 =  .00362
 HF=L*SF = (      82.00)*( .00362) =        .296
--------------------------------------------------------------------------------
 NODE     8.00 : HGL = <   73.208>;EGL= <   74.744>;FLOWLINE= <   65.950>
********************************************************************************
 FLOW PROCESS FROM NODE      8.00 TO NODE      7.00 IS CODE =  3
 UPSTREAM NODE      8.00     ELEVATION =    65.95  (FLOW UNSEALS IN REACH)
--------------------------------------------------------------------------------
 CALCULATE BOX-BEND LOSSES(OCEMA):
 BOX FLOW =      609.00 CFS
 BOX BASEWIDTH =    8.75 FEET          BOX HEIGHT =    7.00 FEET
 CENTRAL ANGLE = 75.000 DEGREES        MANNING'S N =   .01400
 BOX LENGTH =      124.00 FEET         BEND COEFFICIENT(KB) =  .11625
 ADJUSTED CENTRAL ANGEL = (75.000)*(    32.17/    124.00) = 19.460
 FLOW VELOCITY =    9.94 FEET/SEC.     VELOCITY HEAD =  1.535 FEET
 HB=KB*(VELOCITY HEAD) = (  .116)*( 1.535) =     .178
 SF= .00274
 HF=L*SF = (     124.00)*( .00274) =    .340
 TOTAL HEAD LOSSES = HB + HF = (  .178)+(  .340) =    .518
 ===> NORMAL FLOW IS PRESSURE FLOW
--------------------------------------------------------------------------------
 CRITICAL DEPTH(FT) =              5.32
================================================================================
 DOWNSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =      6.78
================================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
--------------------------------------------------------------------------------
 DISTANCE FROM    FLOW DEPTH  VELOCITY    SPECIFIC     PRESSURE+
  CONTROL(FT)       (FT)     (FT/SEC)  ENERGY(FT)  MOMENTUM(POUNDS)
          .000      6.778      10.266      8.415        24659.67
         3.272      6.786      10.253      8.420        24676.73
         6.576      6.795      10.239      8.424        24693.88
         9.911      6.804      10.226      8.429        24711.11
        13.278      6.813      10.212      8.434        24728.43
        16.678      6.822      10.199      8.438        24745.82
        20.111      6.831      10.186      8.443        24763.31
        23.576      6.840      10.173      8.448        24780.88
        27.074      6.849      10.159      8.452        24798.53
        30.605      6.858      10.146      8.457        24816.27
        34.170      6.867      10.133      8.462        24834.08
        37.768      6.875      10.120      8.467        24851.99
        41.401      6.884      10.107      8.471        24869.97
        45.067      6.893      10.094      8.476        24888.04
        48.768      6.902      10.081      8.481        24906.20
        52.504      6.911      10.068      8.486        24924.43
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        56.275          6.920          10.055          8.491          24942.75
        60.081          6.929          10.042          8.496          24961.15
        63.922          6.938          10.029          8.500          24979.63
        67.799          6.947          10.016          8.505          24998.20
        71.712          6.956          10.003          8.510          25016.84
        75.661          6.964           9.991          8.515          25035.57
        79.647          6.973           9.978          8.520          25054.38
        83.670          6.982           9.965          8.525          25073.27
        87.730          6.991           9.952          8.530          25092.25
        91.827          7.000           9.940          8.535          25111.30
  ===> FLOW IS UNDER PRESSURE
       124.000          7.258           9.943          8.794          39476.09
--------------------------------------------------------------------------------
  NODE      7.00 : HGL = <    72.588>;EGL= <    74.225>;FLOWLINE= <    65.810>

********************************************************************************
  FLOW PROCESS FROM NODE      7.00 TO NODE      6.00 IS CODE =  1
  UPSTREAM NODE      7.00     ELEVATION =    65.81  (FLOW IS SUBCRITICAL)
--------------------------------------------------------------------------------
  CALCULATE FRICTION LOSSES(LACFCD):
  BOX FLOW    =      609.00 CFS
  BOX BASEWIDTH =    8.75 FEET          BOX HEIGHT =    7.00 FEET
  BOX LENGTH =      150.00 FEET         MANNING'S N  =    .01400
  ===> NORMAL FLOW IS PRESSURE FLOW
--------------------------------------------------------------------------------
  CRITICAL DEPTH(FT) =              5.32
================================================================================
  DOWNSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =      6.22
================================================================================
  GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
--------------------------------------------------------------------------------
  DISTANCE FROM     FLOW DEPTH   VELOCITY      SPECIFIC       PRESSURE+
   CONTROL(FT)        (FT)      (FT/SEC)     ENERGY(FT)    MOMENTUM(POUNDS)
          .000        6.223       11.181          8.165          23771.27
         5.904        6.254       11.126          8.177          23811.55
        12.072        6.285       11.071          8.189          23853.00
        18.510        6.316       11.016          8.202          23895.62
        25.223        6.347       10.962          8.214          23939.39
        32.217        6.378       10.909          8.227          23984.32
        39.498        6.409       10.856          8.240          24030.38
        47.073        6.440       10.803          8.254          24077.58
        54.947        6.471       10.752          8.268          24125.90
        63.128        6.503       10.700          8.282          24175.33
        71.623        6.534       10.649          8.296          24225.86
        80.438        6.565       10.599          8.310          24277.50
        89.580        6.596       10.549          8.325          24330.22
        99.059        6.627       10.499          8.340          24384.02
       108.880        6.658       10.450          8.355          24438.90
       119.053        6.689       10.402          8.370          24494.84
       129.586        6.720       10.354          8.386          24551.84
       140.487        6.751       10.306          8.402          24609.89
       150.000        6.778       10.266          8.415          24659.67
--------------------------------------------------------------------------------
  NODE      6.00 : HGL = <    71.863>;EGL= <    73.805>;FLOWLINE= <    65.640>

********************************************************************************
  FLOW PROCESS FROM NODE      6.00 TO NODE      5.00 IS CODE =  9
  UPSTREAM NODE      6.00     ELEVATION =    65.64  (FLOW IS SUBCRITICAL)
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 CALCULATE TRANSITION LOSSES(LACFCD):
 BOX FLOW =      609.00 CFS
 TRANSITION STRUCTURE LENGTH =  10.00 FEET
 TOTAL-ANGLE-OF-TRANSITION =  1.430 DEGREES
    BOX      BASEWIDTH   HEIGHT   FRICTION   VELOCITY   VELOCITY HEAD
             (FEET)      (FEET)    FACTOR    (FT/SEC)       (FEET)
 UPSTREAM      8.75        7.00     .01400      11.18          1.94
 DOWNSTREAM    9.00        8.50     .01400      10.61          1.75
 HT = .2*(V1*V1-V2*V2)/64.4
 TRANSITION LOSS COEFFICIENT = .20000      TRANSITION LOSS =    .039
 AVERAGE TRANSITION STRUCTURE FRICTION SLOPE ASSUMED =  .00298
 HF= L*SF = ( 10.00)*(.00298) =    .030
 TOTAL LOSSES = (HT)+(HF) = (  .039)+(  .030) =     .069
-------------------------------------------------------------------------------
 NODE      5.00 : HGL = <   71.989>;EGL= <   73.736>;FLOWLINE= <   65.610>

*******************************************************************************
 FLOW PROCESS FROM NODE      5.00 TO NODE      4.00 IS CODE =  1
 UPSTREAM NODE      5.00     ELEVATION =    65.61  (FLOW IS SUBCRITICAL)
-------------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 BOX FLOW    =     609.00 CFS
 BOX BASEWIDTH =    9.00 FEET          BOX HEIGHT =    8.50 FEET
 BOX LENGTH =     588.00 FEET          MANNING'S N  =    .01400
-------------------------------------------------------------------------------
 NORMAL DEPTH(FT) =       6.41          CRITICAL DEPTH(FT) =       5.22
===============================================================================
 DOWNSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =      6.27
===============================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
-------------------------------------------------------------------------------
 DISTANCE FROM    FLOW DEPTH  VELOCITY    SPECIFIC      PRESSURE+
  CONTROL(FT)       (FT)     (FT/SEC)   ENERGY(FT)   MOMENTUM(POUNDS)
         .000       6.273      10.783       8.080        23780.55
       15.501       6.279      10.774       8.082        23788.82
       31.746       6.284      10.764       8.085        23797.13
       48.801       6.290      10.755       8.087        23805.48
       66.741       6.295      10.745       8.089        23813.87
       85.654       6.301      10.736       8.092        23822.29
      105.638       6.306      10.726       8.094        23830.75
      126.810       6.312      10.717       8.097        23839.24
      149.305       6.317      10.708       8.099        23847.77
      173.284       6.323      10.698       8.101        23856.34
      198.939       6.329      10.689       8.104        23864.94
      226.501       6.334      10.680       8.106        23873.58
      256.252       6.340      10.670       8.109        23882.26
      288.544       6.345      10.661       8.111        23890.97
      323.820       6.351      10.652       8.114        23899.72
      362.648       6.356      10.642       8.116        23908.51
      405.778       6.362      10.633       8.118        23917.33
      454.226       6.367      10.624       8.121        23926.19
      509.416       6.373      10.615       8.123        23935.08
      573.431       6.378      10.606       8.126        23944.01
      588.000       6.379      10.604       8.126        23945.73
-------------------------------------------------------------------------------
 NODE      4.00 : HGL = <   70.293>;EGL= <   72.100>;FLOWLINE= <   64.020>

*******************************************************************************
 FLOW PROCESS FROM NODE      4.00 TO NODE      4.00 IS CODE =  5
 UPSTREAM NODE      4.00     ELEVATION =    64.02  (FLOW IS SUBCRITICAL)
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 CALCULATE JUNCTION LOSSES:
   BOX      FLOW     BASEWIDTH  HEIGHT     SLOPE    FRICTION   ANGLE     FLOWLINE
            (CFS)      (FEET)   (FEET)  (DECIMAL)  FACTOR  (DEGREES)  ELEVATION
 UPSTREAM    609.00     9.00     8.50     .00281     .0140      .00        64.02
DOWNSTREAM   622.00     9.00     8.50     .00281     .0140      -          64.02
LATERAL #1    13.00     3.14     2.00     .00281     .0140    45.00        66.00
LATERAL #2      .00      .00      .00     .00000     .0000      .00          .00
  Q5            .00===Q5 EQUALS BASIN INPUT===
-------------------------------------------------------------------------------
 NORMAL AND CRITICAL DEPTH INFORMATION:
      BOX      CRITICAL DEPTH  NORMAL DEPTH
                   (FEET)         (FEET)
    UPSTREAM       5.220          6.316
   DOWNSTREAM      5.294          6.421
    LATERAL #1      .810          1.016
    LATERAL #2      .000           .000

 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)
 JUNCTION LENGTH =    1.00 FEET
 FRICTION LOSSES =    .000 FEET          ENTRANCE LOSSES =    .000 FEET
 MANHOLE LOSSES = .05*(DOWNSTREAM VELOCITY HEAD) = .05*(  2.39) =  .120 FEET
 JUNCTION LOSSES = (MANHOLE LOSSES)+(FRICTION LOSS)+(ENTRANCE LOSSES)
 JUNCTION LOSSES = (   .120)+(   .000)+(   .000) =     .120
 * USED MANHOLE LOSSES FOR THOMPSON MOMENTUM LOSSES AND
   MODIFIED FLOWDEPTH FOR ASSUMED JUNCTION LOSSES.
-------------------------------------------------------------------------------
 NODE      4.00 : HGL = <    69.588);EGL= <    71.980);FLOWLINE= <    64.020>

*******************************************************************************
 FLOW PROCESS FROM NODE      4.00 TO NODE      3.00 IS CODE =  1
 UPSTREAM NODE      4.00     ELEVATION =    64.02  (FLOW IS SUBCRITICAL)
-------------------------------------------------------------------------------
 CALCULATE FRICTION LOSSES(LACFCD):
 BOX FLOW    =      622.00 CFS
 BOX BASEWIDTH =    9.00 FEET          BOX HEIGHT =    8.50 FEET
 BOX LENGTH =       50.00 FEET         MANNING'S N  =    .01400
-------------------------------------------------------------------------------
 NORMAL DEPTH(FT) =       5.71          CRITICAL DEPTH(FT) =       5.29
===============================================================================
 DOWNSTREAM CONTROL ASSUMED FLOWDEPTH(FT) =      5.29
===============================================================================
 GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:
-------------------------------------------------------------------------------
 DISTANCE FROM     FLOW DEPTH  VELOCITY     SPECIFIC       PRESSURE+
  CONTROL(FT)        (FT)     (FT/SEC)   ENERGY(FT)   MOMENTUM(POUNDS)
          .000       5.294      13.052       7.940        23605.41
          .098       5.310      13.011       7.940        23605.65
          .401       5.327      12.970       7.941        23606.34
          .929       5.343      12.930       7.941        23607.50
         1.702       5.360      12.890       7.942        23609.11
         2.744       5.377      12.850       7.942        23611.18
         4.081       5.393      12.810       7.943        23613.70
         5.747       5.410      12.771       7.944        23616.66
         7.779       5.427      12.732       7.945        23620.08
        10.220       5.443      12.693       7.946        23623.94
        13.124       5.460      12.654       7.948        23628.23
        16.553       5.476      12.616       7.949        23632.97
        20.587       5.493      12.578       7.951        23638.14
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30.878	5.526	12.502	7.955	23649.79
37.413	5.543	12.464	7.957	23656.25
45.134	5.560	12.427	7.959	23663.14
50.000	5.568	12.407	7.960	23666.96

NODE 3.00 : HGL = < 69.124>;EGL= < 71.770>;FLOWLINE= < 63.830>

****

FLOW PROCESS FROM NODE 3.00 TO NODE 2.00 IS CODE = 1
UPSTREAM NODE 3.00 ELEVATION = 63.83 (FLOW IS SUPERCRITICAL)

CALCULATE FRICTION LOSSES(LACFCD):
BOX FLOW = 622.00 CFS
BOX BASEWIDTH = 9.00 FEET BOX HEIGHT = 8.50 FEET
BOX LENGTH = 210.00 FEET MANNING'S N = .01400

NORMAL DEPTH(FT) = 3.38 CRITICAL DEPTH(FT) = 5.29

UPSTREAM CONTROL ASSUMED FLOWDEPTH(FT) = 5.29

GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:

DISTANCE FROM CONTROL(FT)	FLOW DEPTH (FT)	VELOCITY (FT/SEC)	SPECIFIC ENERGY(FT)	PRESSURE+ MOMENTUM(POUNDS)
.000	5.294	13.052	7.940	23605.41
.158	5.217	13.243	7.942	23610.37
.654	5.141	13.439	7.947	23625.45
1.520	5.064	13.642	7.956	23650.94
2.794	4.988	13.851	7.969	23687.19
4.523	4.912	14.066	7.986	23734.54
6.755	4.835	14.288	8.007	23793.36
9.552	4.759	14.517	8.034	23864.05
12.982	4.683	14.754	8.065	23947.02
17.130	4.606	14.999	8.102	24042.73
22.095	4.530	15.251	8.144	24151.65
27.996	4.454	15.513	8.193	24274.30
34.981	4.377	15.783	8.248	24411.21
43.234	4.301	16.064	8.310	24562.99
52.985	4.225	16.354	8.380	24730.24
64.532	4.148	16.655	8.458	24913.66
78.268	4.072	16.967	8.545	25113.96
94.726	3.996	17.291	8.641	25331.93
114.653	3.919	17.628	8.748	25568.39
139.144	3.843	17.979	8.865	25824.28
169.898	3.767	18.343	8.994	26100.55
209.763	3.690	18.722	9.137	26398.29
210.000	3.690	18.724	9.137	26399.63

NODE 2.00 : HGL = < 64.290>;EGL= < 69.737>;FLOWLINE= < 60.600>

****

FLOW PROCESS FROM NODE 2.00 TO NODE 1.00 IS CODE = 1
UPSTREAM NODE 2.00 ELEVATION = 60.60 (HYDRAULIC JUMP OCCURS)

CALCULATE FRICTION LOSSES(LACFCD):
BOX FLOW = 622.00 CFS
BOX BASEWIDTH = 9.00 FEET BOX HEIGHT = 8.50 FEET
BOX LENGTH = 286.00 FEET MANNING'S N = .01400

HYDRAULIC JUMP: DOWNSTREAM RUN ANALYSIS RESULTS

NORMAL DEPTH(FT) = 7.21 CRITICAL DEPTH(FT) = 5.29

UPSTREAM CONTROL ASSUMED FLOWDEPTH(FT) = 3.69

GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:

DISTANCE FROM CONTROL(FT)	FLOW DEPTH (FT)	VELOCITY (FT/SEC)	SPECIFIC ENERGY(FT)	PRESSURE+ MOMENTUM(POUNDS)
.000	3.690	18.724	9.137	26399.63
12.344	3.754	18.404	9.017	26147.94
24.410	3.818	18.095	8.906	25911.51
36.186	3.882	17.796	8.803	25689.72
47.662	3.946	17.507	8.709	25481.96
58.824	4.011	17.227	8.622	25287.66
69.660	4.075	16.956	8.542	25106.31
80.156	4.139	16.693	8.468	24937.40
90.296	4.203	16.438	8.401	24780.48
100.066	4.267	16.191	8.340	24635.10
109.448	4.331	15.951	8.285	24500.86
118.425	4.395	15.718	8.234	24377.37
126.977	4.460	15.492	8.189	24264.26
135.085	4.524	15.273	8.148	24161.20
142.725	4.588	15.059	8.111	24067.85
149.876	4.652	14.851	8.079	23983.91
156.512	4.716	14.649	8.051	23909.10
162.604	4.780	14.453	8.026	23843.14
168.125	4.845	14.261	8.005	23785.76
173.042	4.909	14.075	7.987	23736.72
177.321	4.973	13.893	7.972	23695.80
180.924	5.037	13.717	7.960	23662.76
183.811	5.101	13.544	7.951	23637.39
185.936	5.165	13.376	7.945	23619.51
187.251	5.229	13.212	7.942	23608.91
187.703	5.294	13.052	7.940	23605.41
286.000	5.294	13.052	7.940	23605.41

HYDRAULIC JUMP: UPSTREAM RUN ANALYSIS RESULTS

DOWNSTREAM CONTROL ASSUMED FLOWDEPTH(FT) = 6.55

GRADUALLY VARIED FLOW PROFILE COMPUTED INFORMATION:

DISTANCE FROM CONTROL(FT)	FLOW DEPTH (FT)	VELOCITY (FT/SEC)	SPECIFIC ENERGY(FT)	PRESSURE+ MOMENTUM(POUNDS)
.000	6.550	10.548	8.279	24765.23
22.319	6.576	10.506	8.291	24811.27
46.071	6.603	10.464	8.304	24858.11
71.384	6.629	10.423	8.317	24905.73
98.404	6.655	10.381	8.330	24954.14
127.297	6.681	10.341	8.343	25003.32
158.255	6.708	10.300	8.356	25053.28
191.502	6.734	10.260	8.370	25104.01
227.300	6.760	10.220	8.383	25155.50
265.959	6.787	10.180	8.397	25207.76
286.000	6.799	10.162	8.403	25233.02

END OF HYDRAULIC JUMP ANALYSIS

* NOTE: PRESSURE + MOMENTUM BALANCE OCCURS 218.52 FEET FROM NODE 1.00

```
 NODE      1.00 : HGL = <    66.550>;EGL= <    68.279>;FLOWLINE= <    60.000>

**********************************************************************************
  DOWNSTREAM BOX FLOW CONTROL DATA:
  NODE NUMBER =      1.00              FLOWLINE ELEVATION =     60.00
  BOX FLOW =       622.00 CFS
  BOX BASEWIDTH =    9.00 FEET         BOX HEIGHT =    8.50 FEET
  ASSUMED DOWNSTREAM CONTROL HGL =     66.550
==================================================================================
  END OF GRADUALLY VARIED FLOW ANALYSIS
```