ACK ENGINEERS, INC.

AGK ENGINEERS, INC.
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July 15, 1991

Mr. Mark Wavering, P.E.
INCA ENGINEERS, INC.
1702 E. Highland Avenue, Suite 207
Phoenix, AZ 85016

Reference: Bush Highway Box Culvert
FCD Contract 90-46
AGK Job No. 425.40

Dear Mr. Wavering:

Pursuant to our agreement dated January 22, 1991, AGK Engineers is pleased to submit four (4) copies of the hydraulic report for culvert modification on Bush Highway at Spook Hill Floodway.

The analysis was performed on the basis of information obtained from the Flood Control District of Maricopa County, the Soil Conservation Service, and the Maricopa County Highway Department as-built plans. Refinement on structural dimensions and elevations may be required during the design phase of this project.

Very truly yours,

AGK ENGINEERS, INC.

Samuel E. Kao, Ph.D., P.E.
Vice President

SEK/kp

INCA ENGINEERS, INC.

A HYDRAULIC REPORT FOR CULVERT MODIFICATIONS ON BUSH HIGHWAY AT SPOOK HILL FLOODWAY

AGK Project No. 425.40

JULY 1991

Registered Professional Engineer (Civil)
CERTIFICATE NO.
10283
SAMUEL E.
KAO
Date Signed 7-15-91
ARIZONA, U.S.A.

Prepared by:

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AGK ENGINEERS, INC.

A HYDRAULIC REPORT FOR CULVERT MODIFICATION ON BUSH HIGHWAY AT SPOOK HILL FLOODWAY

GENERAL

On January 22, 1991, AGK Engineers, Inc. was retained by INCA Engineers, Inc. to investigate the hydraulic impacts resulting from modification of the existing Bush Highway concrete box culvert at Spook Hill Floodway, and to provide design for erosion control measures at both ends of the culvert.

The study was performed on the basis of the assumption that the alignment of Spook Hill Floodway will remain at the same location. Refinement on structural dimensions and elevations may be required during the design phase of this project.

EXISTING SITE CONDITIONS

The existing culvert is located on Bush Highway, approximately 3.5 miles north of McDowell Road in Mesa. It was constructed in 1962 to serve as the conveyance structure for Spook Hill Floodway. The culvert consists of a double 10' x 7' reinforced concrete box (RCB), at a 45 degree skew to the road, with a length of 81.5 feet. The slope of the culvert is approximately 2.8 percent. According to a field survey, the invert elevations of the culvert are as follows:

Location	Inlet Elevation	Outlet Elevation
North Barrel	1336.25	1336.80
South Barrel	1333.91	1334.49

The upstream channel is narrow and deep, formed with coarse materials on the bottom and dense vegetation on the banks. The slope of the channel is approximately 2.2 percent. As shown on Plate 1, the channel has a sharp turn at the inlet of the culvert.

The downstream channel, on the other hand, is wide and uniform. The bottom of the channel is composed of fine sands, with an average slope of 1.3 percent. A section of grouted riprap is provided immediately downstream of the culvert outlet to prevent erosion of the channel bottom.

The channel banks in the vicinity of the culvert inlet and outlet are protected by gabions and rock riprap. The conditions of the existing upstream and downstream channels are shown in the attached photographs.

FUTURE SITE CONDITIONS

As instructed by the Flood Control District of Maricopa County (FCDMC), a double 10' x 7' pre-cast box will be installed on the southwest side of the existing box culvert to increase the capacity of the conveyance structure.

The downstream channel will be improved by the Soil Conservation Service (SCS) to be a U-Channel with reinforced concrete walls and grouted rock riprap floor in the near future. The width of the new channel will be 40 feet. According to SCS, no plan has been made for channel improvements upstream of the culvert.

In the 1970's, SCS performed a geotechnical investigation at the project site. The investigation consisted of 12 test holes varying in depth from 3 to 16 feet. All holes near the culvert encountered weathered granite at depths ranging from 3 to 7 feet.

HYDRAULIC ANALYSIS

As estimated by SCS, the 100-year peak design flow at the culvert is 2,650 cfs. The water surface profiles for both upstream and downstream of the culvert were computed in this study by use of the HEC-2 computer program. A Manning's roughness coefficient of 0.035 was used for the upstream channel section and 0.045 and 0.055 for the left and right banks. As for the downstream channel, a value of 0.030 was used for the channel section and 0.035 for both left and right banks.

UPSTREAM CHANNEL

DOWNSTREAM END

OF EXISTING CULVERT

DOWNSTREAM CHANNEL

Channel cross sections used in the computation were obtained from the field survey. The coefficients of contraction and expansion were respectively assumed to be 0.1 and 0.3.

Results of the hydraulic analysis indicated that at the design flow of 2,650 cfs, both the upstream and downstream channels would operate under supercritical flow conditions. However, the headwater at the culvert entrance would reach an elevation of 1345.20, which is well above the critical depth at the culvert entrance. Therefore, a mild hydraulic jump would occur near the entrance when the depth of flow changes from a supercritical condition to a subcritical condition. The influence of backwater created by the culvert headwater is expected to reach as far as Sta. 8+00 on the upstream channel. The computed water surface profiles are illustrated on Plate 1.

PROPOSED IMPROVEMENTS FOR EROSION MITIGATION

Downstream Area

The proposed downstream improvements consist of a concrete apron with a 4-foot rock riprap forming a transition between the edge of apron and the existing channel bottom. The length of the proposed apron will be 10 feet, with a slope similar to the box culvert. The floor of the apron will match the invert of the culvert.

The existing wingwalls and gabions will be removed to make room for the new construction. A pair of straight wingwalls will be placed at the apron because this type of arrangement would be easier for SCS to tie the culvert to the future channel. In addition to the straight wingwalls, another pair of concrete wingwalls will be placed at the culvert outlet (as shown on Plate 2) to provide interim protection for channel embankments. These interim wingwalls will be removed when the SCS downstream channel improvement begins.

Upstream Area

The proposed upstream improvements include an area of grouted riprap on the north embankment behind the north wingwall and a 60-foot long south wingwall supplemented with grouted rock riprap, as shown on Plate 2. The embankment protection on the north will be terminated near the right-of-way line. The embankment protection along Bush Highway will be extended to Sta. 8+00, which is the limit of this project.

Based on field investigations, the SCS personnel felt that the bottom of the upstream channel is composed of rocky materials, and hence riprap would not be required. However, due to possible occurrence of hydraulic jump near the culvert entrance, an area of grouted riprap is proposed to be installed on the channel floor immediately upstream of the culvert, as shown on Plate 2. In addition, a 4-foot deep concrete cut-off wall is proposed at the culvert inlet.

DESIGN OF RIPRAP

During a review meeting on April 2, 1991, representatives from FCDMC and SCS decided to use the Federal Highway Administration (FHWA) criteria and guidelines for riprap design in this project. The detailed procedures and calculations for riprap design are presented in the Appendix.

Riprap Along Embankment

According to FHWA, the size of stone needed to protect a streambed or highway embankment from erosion by a current moving parallel to the embankment can be determined by the velocity method. Results from HEC-2 analysis indicated that the highest flow velocity within the project limits occurs in the vicinity of Sta. 8+00. The velocity was computed to be 19.6 fps, and the required median stone size (D_{50}) was estimated to be 13.8 inches.

Riprap at North Culvert Inlet

There is a sharp change of channel alignment at the entrance of the culvert. At the present time, FHWA does not have any specific guidelines for sizing riprap at channel bends. However, the California Highway Division recommends doubling the velocity against the stone as determined for straight alignment before entering the nomographs for estimating stone size at channel bends. The entrance velocity at the culvert was computed to be 9.5 fps, and the required D_{50} was estimated to be 10.8 inches.

Riprap Gradation and Thickness

By use of the FHWA guidelines, the gradation of the riprap stone was estimated as follows:

1.	Minimum weight of each stone:	25 pounds
2.	50% of stone weight:	greater than 100 pounds
3.	Maximum weight of each stone:	700 pounds

The minimum thickness of the riprap layer was determined to be 24 inches, which is approximately two times the size of D_{50}.

Typical Section of Grouted Riprap

A typical section of grouted riprap with toe trench is presented in Figure 1. Filter fabric will be placed under the stone layer as shown on the drawings. The top of riprap will be at Elev. 1346.0 The depth of the toe trench will be 5 feet or the depth to bedrock, whichever is smaller. The toe trench will not be required when the adjoining channel floor is also protected with grouted riprap.

The material and method of placement of filter fabric will be specified in accordance with ADOT Std. Specifications Section 913. The installation of grouted riprap will be specified according to MAG Std. Specifications Section 220.5.

BIBLIOGRAPHY AND REFERENCES

1. U.S. Department of the Army. Corps of Engineers, Hydrologic Engineering Center. *Generalized Computer Program 723-X6-L202A, HEC-2 Water Surface Profiles.* Davis, California, February 1989.

2. Chow, Ven T. *Open Channel Hydraulics.* New York: McGraw-Hill Book Company, 1959.

3. Federal Highway Administration. *Use of Riprap for Bank Protection,* Hydraulic Engineering Circular No. 11, June 1967.

4. Richardson, E.V., Simons, D.B. Julien, P.Y., *Highways in the River Environment,* Federal Highway Administration, January 1987.

5. Federal Highway Administration, *Hydraulic Design of Highway Culverts,* Hydraulic Design Series No. 5, September 1985.

6. Maricopa County Highway Department, *As-built Plans for Power Road, S-388(3),* July 1962.

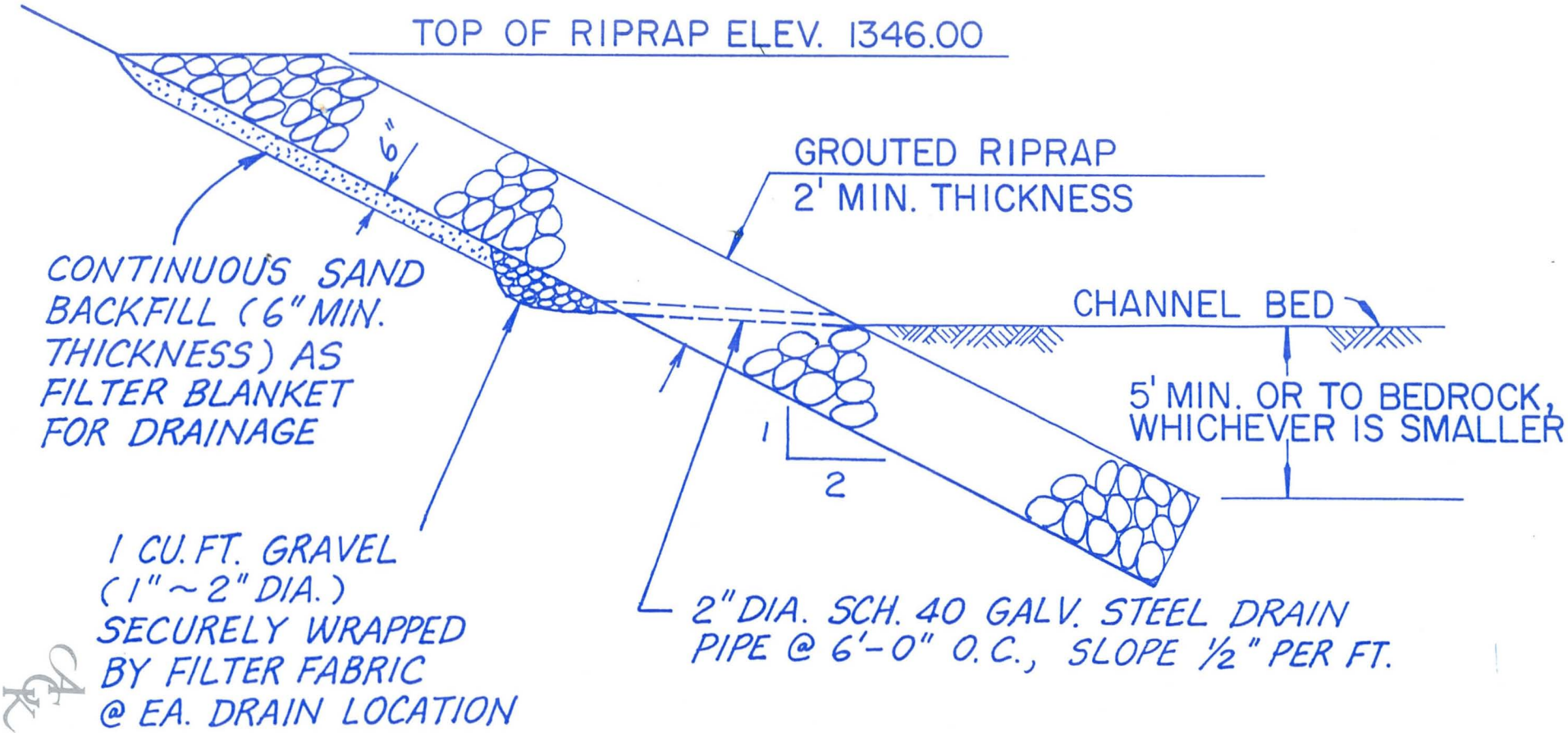


FIGURE 1

TYPICAL SECTION OF GROUTED RIPRAP

CAGK ENGINEERS, INC.

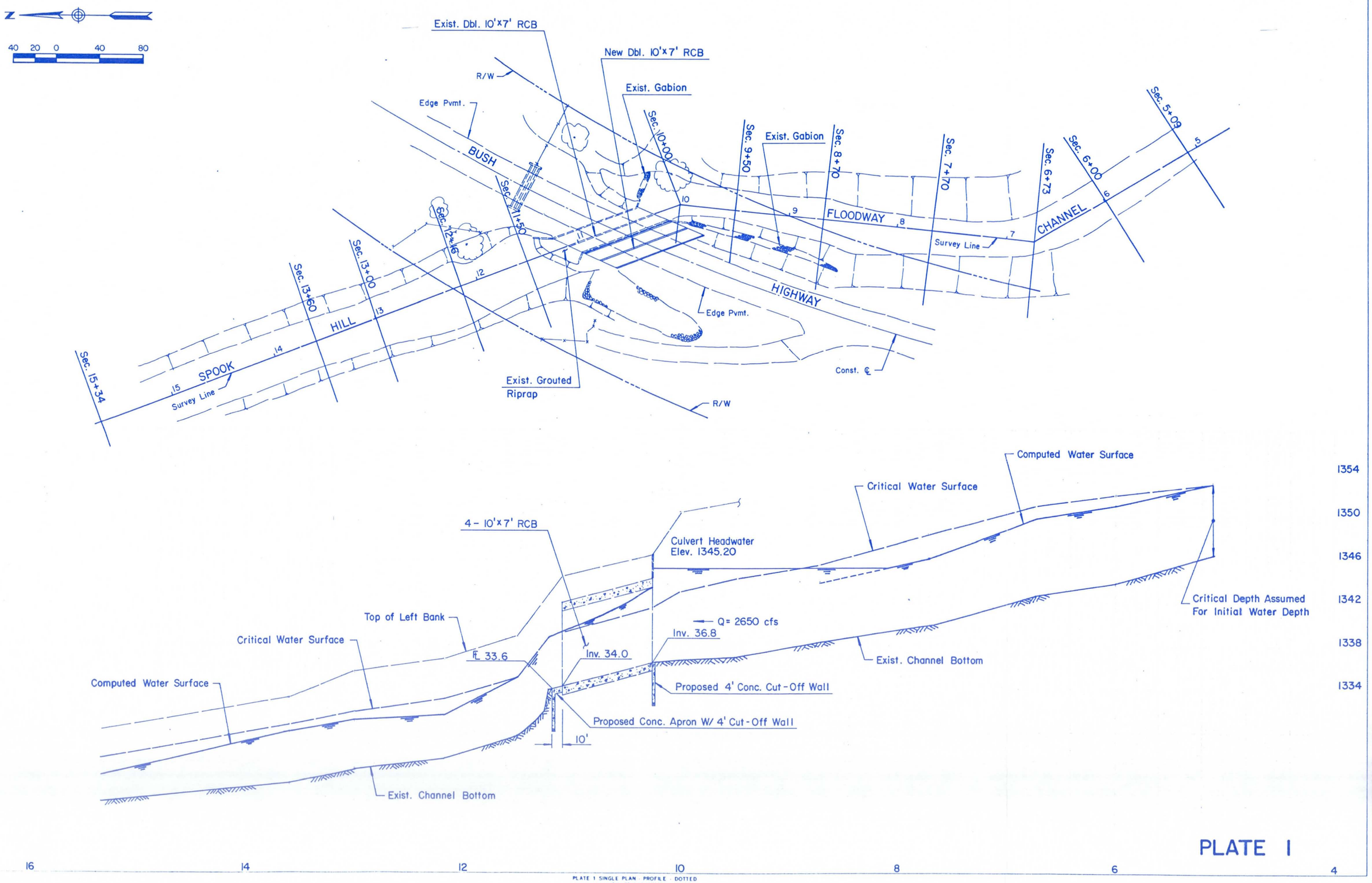
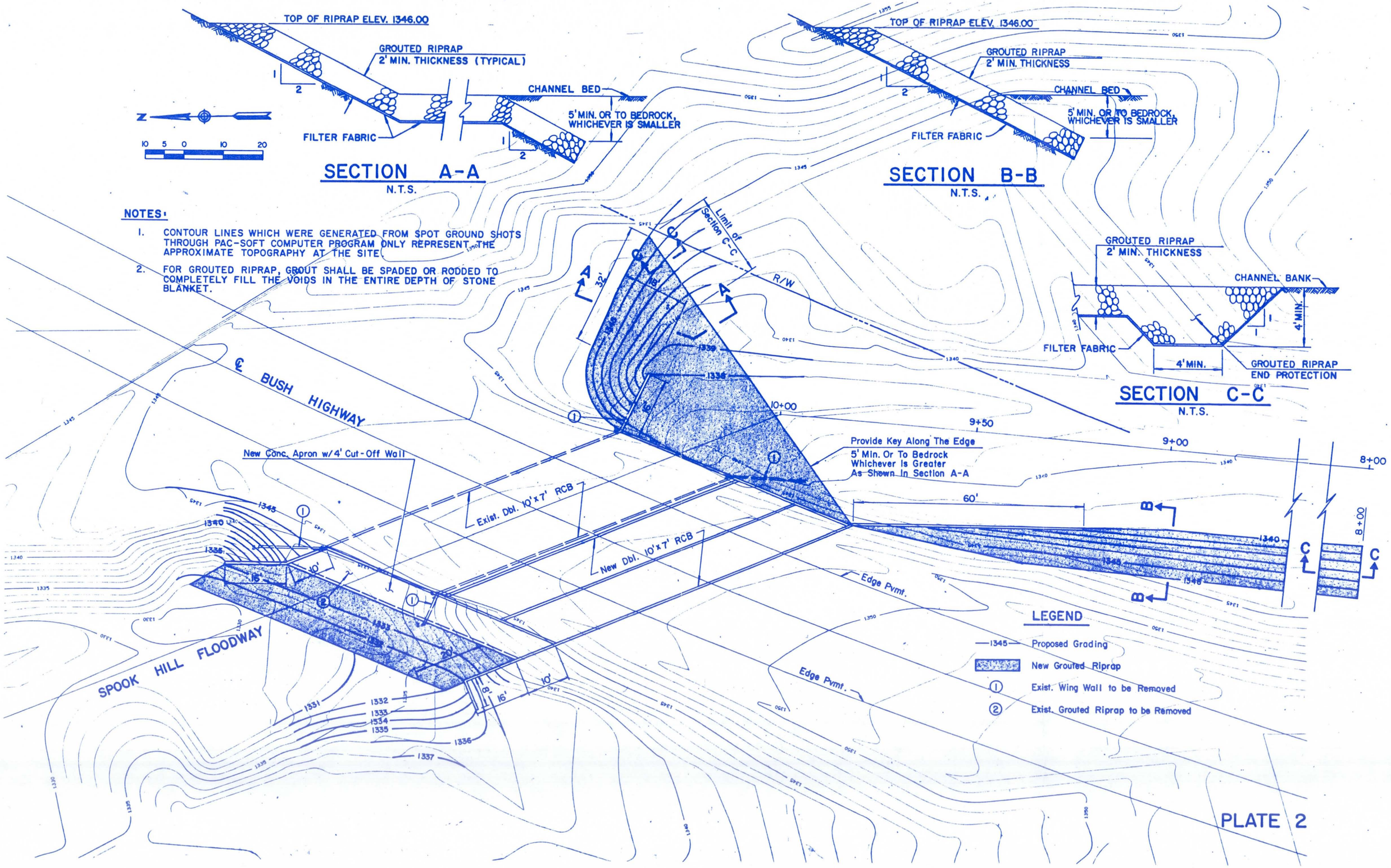


PLATE 1

PLATE 1 SINGLE PLAN - PROFILE - DOTTED
CHARLES BRINNINGER COMPANY
MADE IN U.S.A.



NOTES:

1. CONTOUR LINES WHICH WERE GENERATED FROM SPOT GROUND SHOTS THROUGH PAC-SOFT COMPUTER PROGRAM ONLY REPRESENT THE APPROXIMATE TOPOGRAPHY AT THE SITE.
2. FOR GROUTED RIPRAP, GROUT SHALL BE SPADED OR RODDED TO COMPLETELY FILL THE VOIDS IN THE ENTIRE DEPTH OF STONE BLANKET.

PLATE 2

APPENDIX

ENGINEERING CALCULATIONS

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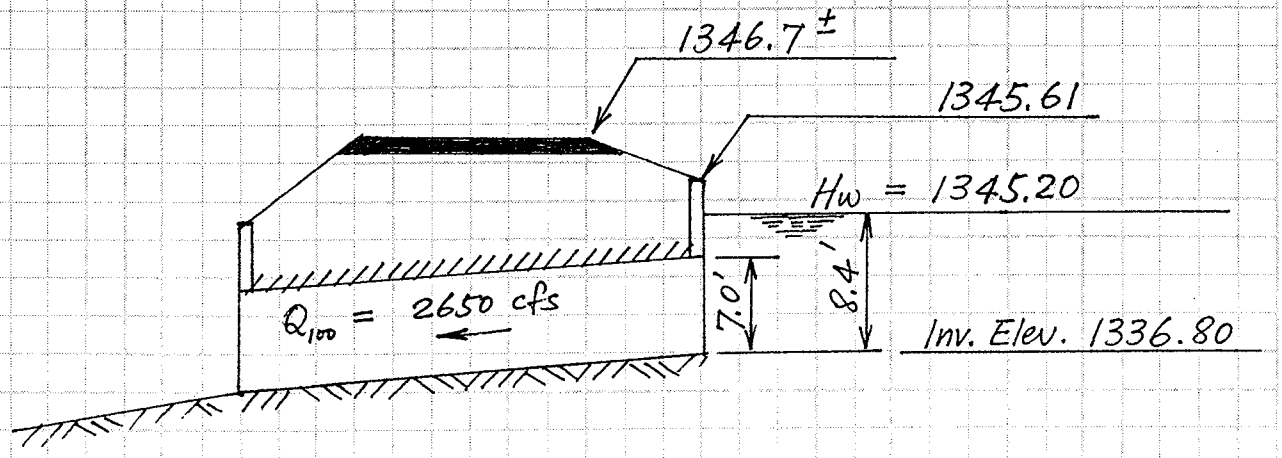
SHEET 1 OF ____
BY SEK DATE 3/4/91
CHECK ____ DATE ____

CLIENT INCA / FCDMC
JOB Bush Hwy Box Culvert
JOB NO. 425.40

UPSTREAM CONDITION

1. Design Flow = 2650 cfs
2. Because the downstream channel is designed by SCS as supercritical flow, the hydraulic condition of the RCB would be inlet control.
3. Design Width = 4 × 10' = 40'
4. Discharge per Barrel = 2650 / 4 = 663 cfs
5. Per-ft Discharge = 2650 / 40' = 67 cfs/ft
6. From Chart 1 on next sheet,
   Headwater Depth in terms of Height $H_w/D = 1.2$
7. Headwater Depth D = 1.2 × 7.0' = 8.4'



8. Edge of Pavement Elev. 1346.7 > Headwater Elev. 1345.20
9. Entrance Velocity $V_o = Q/A = 2650/(40' \times 7') = 9.46$ fps

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SHEET 2 OF ____
BY SEK DATE 3/4/91
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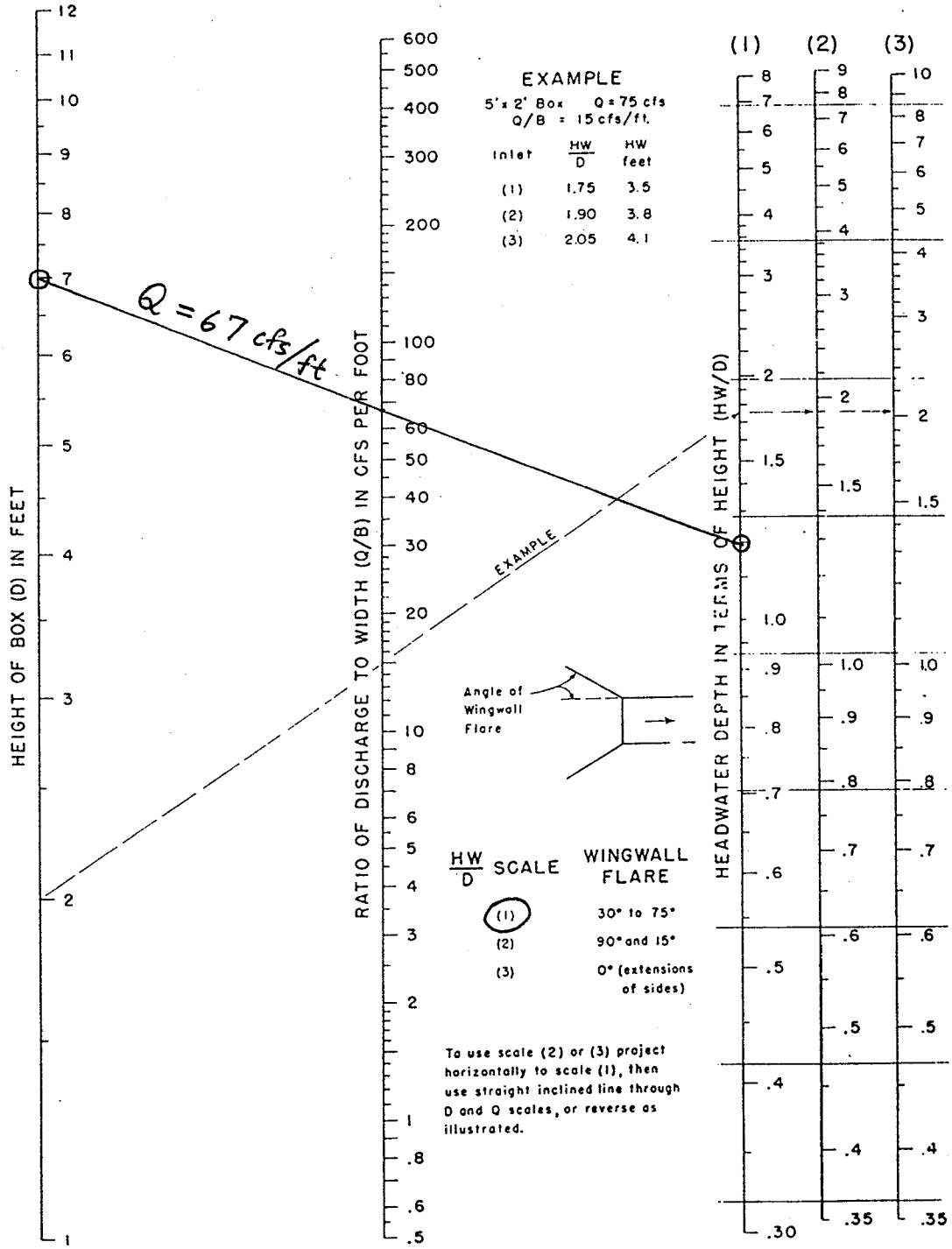
CLIENT INCA / FCDMC
JOB Bush Hwy Box Culvert
JOB NO. 425.40

CHART I



H = 7'

HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

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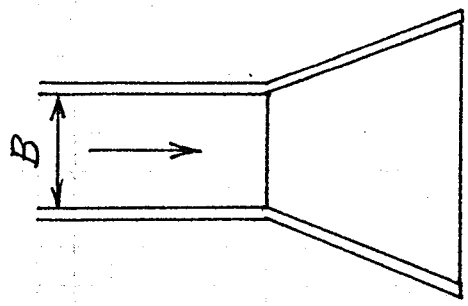
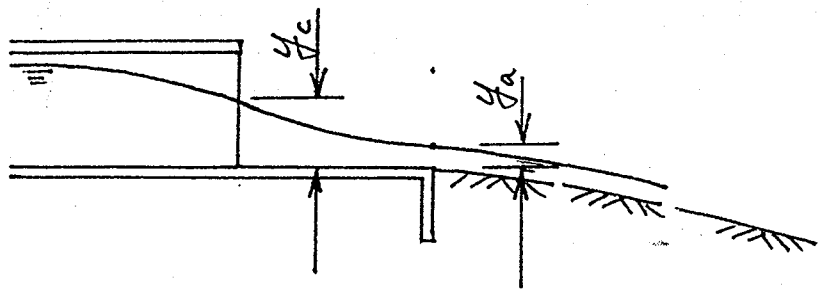
CLIENT INCA / FCDMC

JOB Bush Hwy Box Culvert JOB NO. 425.40

DOWN STREAM CONDITION

1. Because the downstream slope is steep, it is appropriate to assume a critical depth at the culvert outlet.





$$y_c = \sqrt[3]{\frac{Q^2}{g B^2 N^2}} = 0.315 \left(\frac{Q}{NB}\right)^{2/3} = 0.315 \left(\frac{2650}{4 \times 10'}\right)^{2/3} = 5.20'$$

where Q = design peak flow in cfs

B = net culvert width in ft

y_c = critical depth in ft

N = number of barrels for box culvert

2. Velocity at the outlet, $V_c = \frac{Q}{N \cdot B \cdot y_c} = \frac{2650}{4 \times 10' \times 5.20'} = 12.9$ fps

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SHEET 4 OF

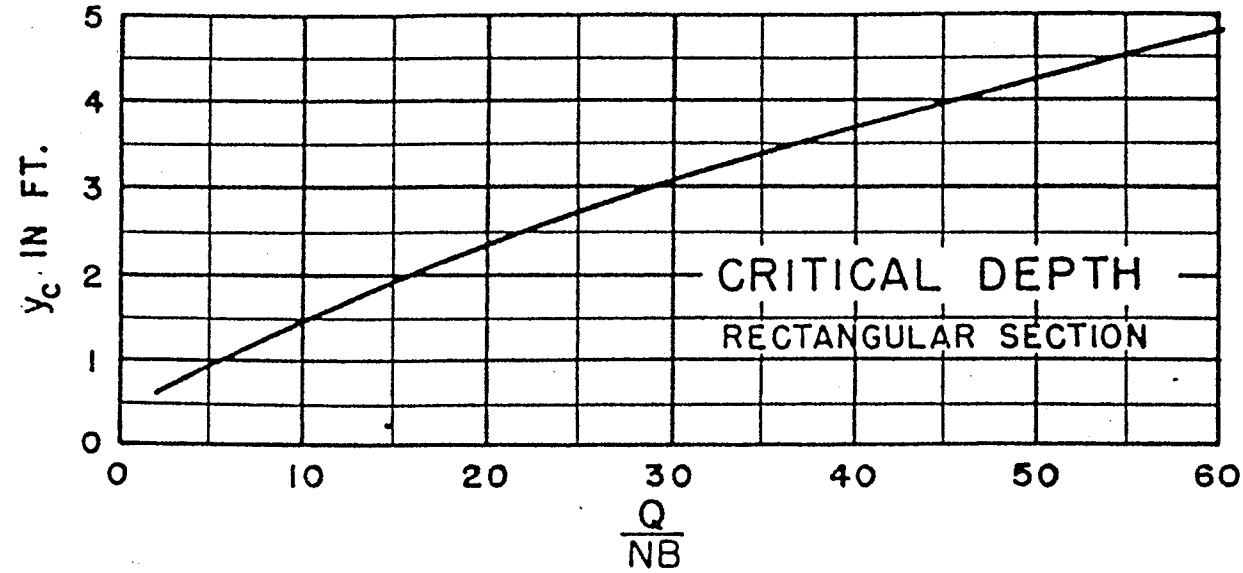
BY DATE

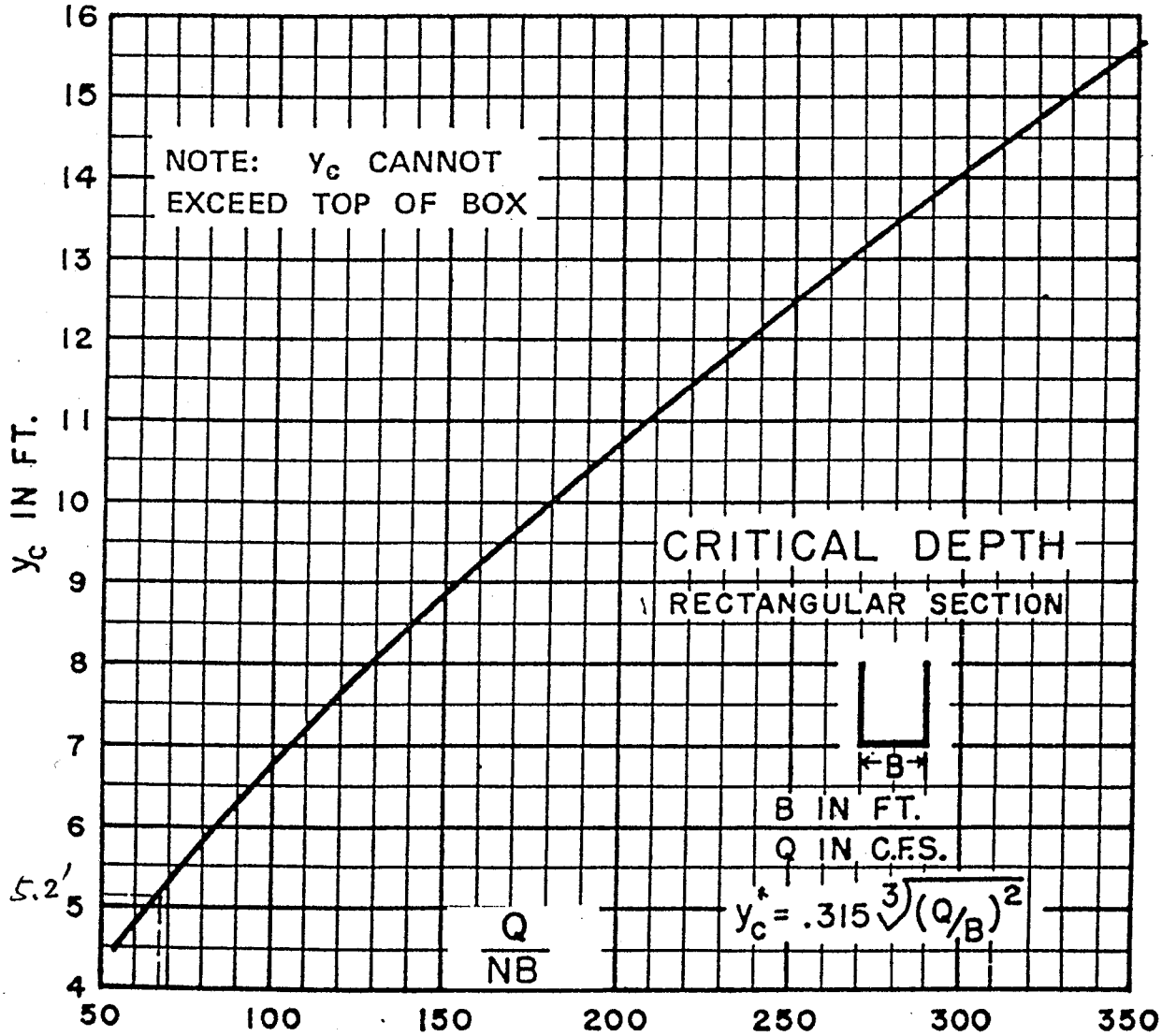
CHECK DATE

CLIENT

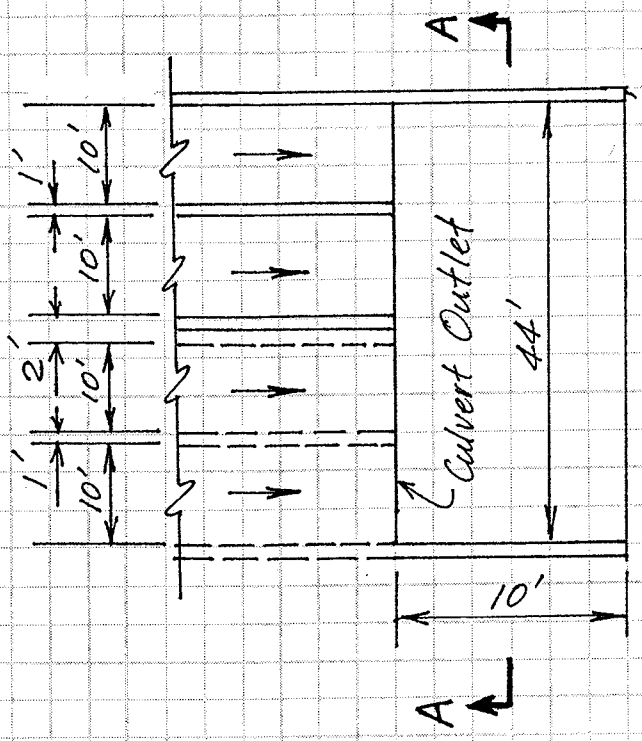
JOB

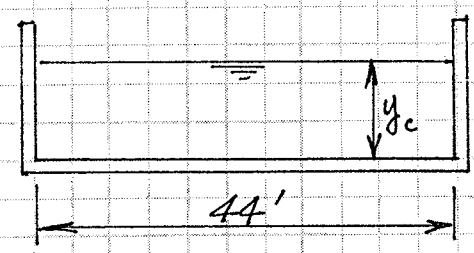
JOB NO. 425.40





3. At the section immediately downstream of the culvert outlet, the net width of the channel is expanded to 44'.





SECTION A-A

y_c at immediately downstream of the culvert is

$$y_c = 0.315\left(\frac{2650}{44'}\right)^{2/3} = 4.85'$$

Velocity at immediately downstream of the culvert is

$$V_c = \frac{2650}{44 \times 4.85} = 12.4 \text{ fps}$$

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SHEET 6 OF ____
BY SEK DATE 3/10/91
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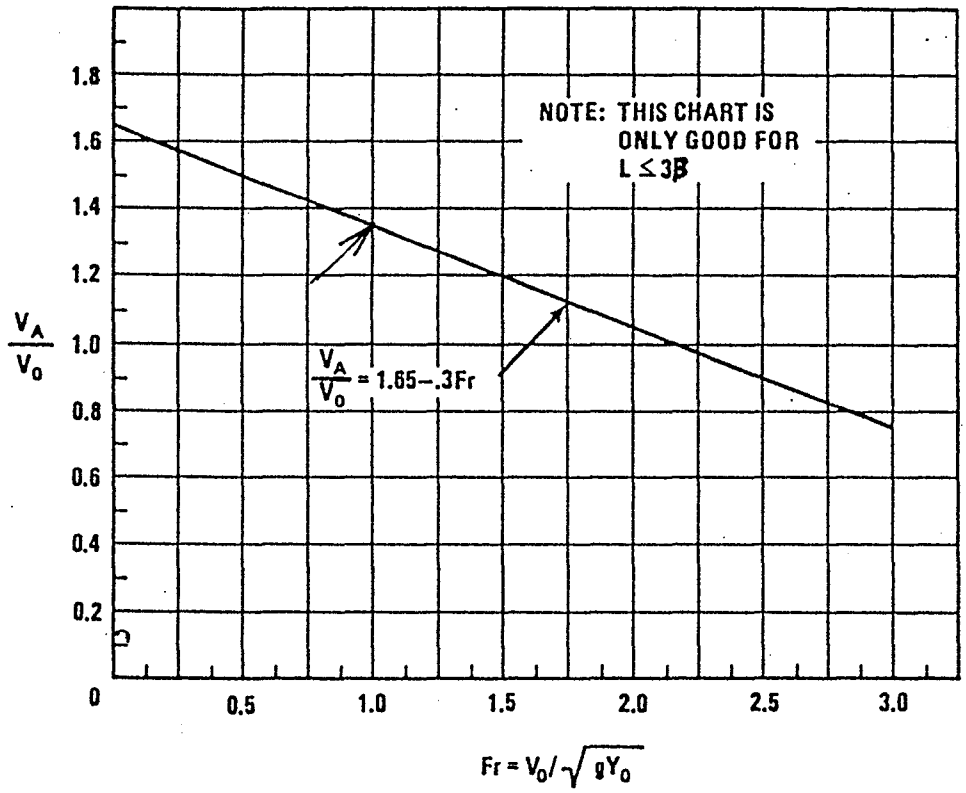
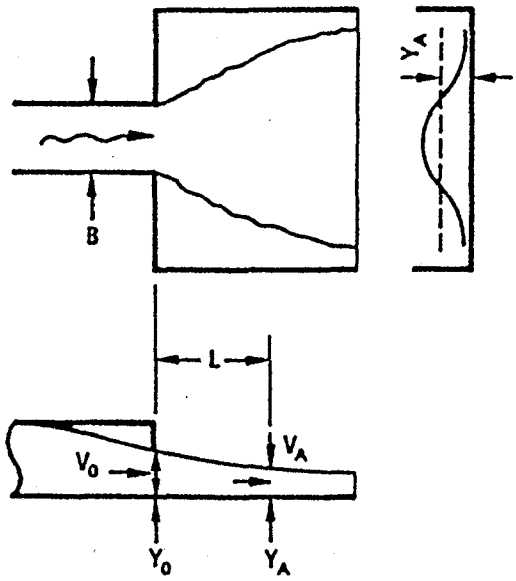
CLIENT INCA / FCDMC
JOB Bush Hwy Box Culvert
JOB NO. 425.40

AVERAGE VELOCITY FOR ABRUPT EXPANSION BELOW RECTANGULAR OUTLET FROM





L = DISTANCE TO DESIRED VELOCITY
B = WIDTH OF CULVERT
Y_0 = BRINK DEPTH
Y_A = AVERAGE DEPTH OF FLOW
V_0 = VELOCITY AT CULVERT OUTLET
V_A = AVERAGE VELOCITY IN EXPANSION

When $F_r = 1.0$ (Critical Flow)

$$V_A = \frac{V_0}{(1.65 - 0.3 \times 1)} = \frac{V_0}{1.35}$$

$$= 12.4/1.35 \cong 9.20 \text{ fps}$$

```
1*******************************************************
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 *  VERSION OF SEPTEMBER 1988                          *
 *  ERROR: 01                                          *
 *  UPDATED: 16 FEBRUARY 1989                          *
 *  RUN DATE     3/22/91    TIME     0:48:39           *
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*  U.S. ARMY CORPS OF ENGINEERS        *
*  THE HYDROLOGIC ENGINEERING CENTER   *
*  609 SECOND STREET, SUITE D          *
*  DAVIS, CALIFORNIA 95616             *
*  (916) 756-1104                      *
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EXISTING UPSTREAM REACH

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X     X  XXXXXXX   XXXXX              XXXXX
X     X  X        X     X            X     X
X     X  X        X                        X
XXXXXXX  XXXX     X          XXXXX    XXXXX
X     X  X        X                  X
X     X  X        X     X            X
X     X  XXXXXXX   XXXXX              XXXXXXX
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END OF BANNER

3/22/91 0:48:40 PAGE 1

THIS RUN EXECUTED 3/22/91 0:48:40

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**************************************************
  HEC2 RELEASE DATED SEPT 88

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T1 BUSH HWY BOX CULVERT - UPSTREAM SECTIONS (BHCHUP.DAT/OUT)
T2 INCA ENGINEERS/FCDMC 90-46/AGK JOB NO. 425.40
T3 EXISTING UPSTREAM CHANNEL (Q=2650 CFS)

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	0	0	0	1	-1	0	0	2650.	1348.5	0

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1	0	-1	0	0	0	-1	0	0	15

NC	.045	.055	.035	.1	.3					
X1	5.09	8.0	84.9	124.9						
GR	1367.0	54.6	1352.2	75.0	1352.5	81.7	1348.0	84.9	1346.5	100.0
GR	1349.5	124.9	1363.6	164.0	1365.2	176.6				
X1	6.00	14.0	82.7	109.3	91.0	91.0	91.0			
GR	1376.2	33.6	1365.1	61.5	1349.9	76.4	1345.4	82.7	1343.9	89.3
GR	1345.7	102.0	1347.4	103.8	1347.9	109.3	1351.6	116.1	1352.2	120.4
GR	1356.8	133.3	1359.1	143.7	1358.8	157.9	1360.9	173.2		
X1	6.73	13.0	92.7	115.0	80.0	55.0	70.0			
GR	1368.3	39.3	1363.9	56.3	1355.5	78.0	1344.2	92.7	1343.2	100.0
GR	1342.7	107.0	1344.1	110.8	1343.9	115.0	1347.8	119.3	1349.3	128.1
GR	1348.6	143.6	1353.8	153.4	1357.7	181.9				
NC				.2	.4					
X1	7.70	16.0	84.4	108.5	100.0	100.0	100.0			

```
GR   1363.0     37.8    1349.5     51.0    1346.3     64.4    1345.5     76.0    1343.3     83.0
GR   1341.8     84.4    1339.9     94.2    1341.8    101.3    1341.8    108.5    1347.1    115.5
GR   1346.6    134.9    1353.5    150.7    1353.8    160.4    1350.6    179.7    1357.1    195.2
GR   1359.3    210.3

X1      8.70     16.0      78.5    120.0     100.0    100.0     100.0
GR   1353.8     40.1    1345.7     58.3    1343.8     62.7    1344.2     71.6    1343.4     75.8
GR   1341.7     78.5    1341.6     86.8    1340.4     94.5    1340.7     96.9    1339.7    102.0
GR   1339.7    108.7    1338.4    112.1    1339.5    119.2    1341.0    120.0    1350.1    140.3
GR   1352.4    155.1

X1      9.50     15.0      81.6    123.9      80.0     80.0      80.0
X3        10
GR   1350.4     60.9    1342.1     76.1    1341.3     78.1    1341.1     81.6    1339.0     91.0
GR   1338.8     96.9    1337.9    103.9    1337.0    106.1    1338.1    110.3    1338.7    115.8
GR   1343.5    123.9    1345.0    136.5    1342.0    168.0    1342.2    179.3    1355.4    221.1
```



```
X1     10.00     14.0      84.0    114.2      40.0     55.0      50.0
GR   1348.4     73.8    1343.3     83.8    1338.8     84.0    1338.7     85.8    1337.4     89.1
GR   1336.7     97.3    1337.4    106.9    1338.6    114.2    1339.5    119.6    1339.0    120.6
GR   1339.5    130.1    1342.6    144.3    1345.5    159.1    1351.4    196.9
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

*PROF 1

CRITICAL DEPTH TO BE CALCULATED AT ALL CROSS SECTIONS

CCHV=     .100 CEHV=     .300
*SECNO 5.090
3720 CRITICAL DEPTH ASSUMED
     5.09     6.41  1352.91  1352.91  1348.50  1355.16     2.25      .00      .00  1348.00
    2650.      45.    2547.      58.      13.     208.      16.       0.       0.  1349.50
      .00     3.56    12.25     3.58     .045     .035     .055     .000  1346.50    74.02
  .009333       0.       0.       0.        0       22        0      .00    60.35   134.37

FLOW DISTRIBUTION FOR SECNO=      5.09          CWSEL=   1352.91

STA=      74.      75.      82.      85.     125.     134.
  PER Q=      .0       .3      1.4     96.1      2.2
   AREA=      .4      3.8      8.5    207.9     16.2
    VEL=     1.4      2.2      4.3     12.3      3.6
  DEPTH=      .4       .6      2.7      5.2      1.7

*SECNO 6.000

3301 HV CHANGED MORE THAN HVINS

     6.00     7.11  1351.01  1351.98      .00  1354.99     3.98      .00      .17  1345.40
    2650.      176.    2437.      38.      22.     147.       9.       0.       0.  1347.90
      .00     8.07    16.54     4.24     .045     .035     .055     .000  1343.90    75.31
```

```
 .016270      0.       0.       0.       7       11       0      .00    39.70   115.01
0
FLOW DISTRIBUTION FOR SECNO=      6.00          CWSEL=   1351.01

STA=      75.      76.      83.     109.     115.
  PER Q=       .1      6.6     92.0      1.4
   AREA=       .6     21.2    147.3      8.9
    VEL=      2.2      8.2     16.5      4.2
  DEPTH=       .6      3.4      5.5      1.6
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS   BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA   LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

*SECNO 6.730
     6.73     7.07  1349.77  1350.87      .00  1353.60     3.83     1.34      .04  1344.20
    2650.     131.    2336.     183.      20.     141.      42.       0.       0.   1343.90
      .00     6.49    16.62     4.40     .045     .035     .055     .000  1342.70    85.45
  .013426      91.      91.      91.        8        8        0      .00    60.36   145.81
0
FLOW DISTRIBUTION FOR SECNO=      6.73          CWSEL=   1349.77

STA=      85.      93.     115.     119.     128.     144.     146.
  PER Q=      4.9     88.1      4.1      1.4      1.3       .1
   AREA=     20.2    140.5     16.9     10.8     12.7      1.3
    VEL=      6.5     16.6      6.4      3.5      2.7      2.0
  DEPTH=      2.8      6.3      3.9      1.2       .8       .6

CCHV=     .200 CEHV=     .400
*SECNO 7.700

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE

     7.70     6.23  1346.13  1348.18      .00  1351.93     5.80     1.28      .39  1341.80
    2650.     149.    2422.      79.      20.     121.      12.       1.       0.   1341.80
      .00     7.39    20.09     6.37     .045     .035     .055     .000  1339.90    66.78
  .026802      80.      70.      55.        9        8        0      .00    47.45   114.23
0
FLOW DISTRIBUTION FOR SECNO=      7.70          CWSEL=   1346.13

STA=      67.      76.      83.      84.     109.     114.
  PER Q=       .3      3.5      1.9     91.4      3.0
   AREA=      2.9     12.2      5.0    120.6     12.4
    VEL=      2.5      7.6      9.8     20.1      6.4
  DEPTH=       .3      1.7      3.6      5.0      2.2

*SECNO 8.700

3301 HV CHANGED MORE THAN HVINS
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS   BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA   LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
```

```
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

     8.70     5.40  1343.80  1345.30      .00  1348.50     4.70     2.99      .44  1341.70
    2650.      22.    2577.      51.       4.     146.       9.       1.       0.   1341.00
      .00     5.81    17.62     5.82     .045     .035     .055     .000  1338.40    73.72
  .033584     100.     100.     100.        7        8        0      .00    52.51   126.24
0
 FLOW DISTRIBUTION FOR SECNO=      8.70          CWSEL=   1343.80

 STA=      74.      76.      79.     120.     126.
   PER Q=       .0       .8     97.3      1.9
    AREA=       .4      3.4    146.3      8.7
     VEL=      2.0      6.3     17.6      5.8
   DEPTH=       .2      1.2      3.5      1.4

 *SECNO 9.500

 3265 DIVIDED FLOW


 3301 HV CHANGED MORE THAN HVINS

 3685 20 TRIALS ATTEMPTED WSEL,CWSEL
 3693 PROBABLE MINIMUM SPECIFIC ENERGY
 3720 CRITICAL DEPTH ASSUMED
     9.50     7.18  1344.18  1344.18      .00  1345.96     1.78     1.54     1.24  1341.10
    2650.     105.    2363.     182.      19.     210.      57.       2.       0.   1343.50
      .01     5.43    11.24     3.20     .045     .035     .055     .000  1337.00    72.29
  .008771     100.     100.     100.       20       14        0      .00    97.84   185.58
0
 FLOW DISTRIBUTION FOR SECNO=      9.50          CWSEL=   1344.18

 STA=      72.      76.      78.      82.     124.     130.     168.     179.     186.
   PER Q=       .4      1.0      2.5     89.2       .1      2.5      3.7       .6
    AREA=      4.0      5.0     10.4    210.3      2.0     25.0     23.5      6.2
     VEL=      2.9      5.4      6.4     11.2      1.2      2.7      4.1      2.4
   DEPTH=      1.0      2.5      3.0      5.0       .3       .7      2.1      1.0

 *SECNO 10.000
 3685 20 TRIALS ATTEMPTED WSEL,CWSEL
 3693 PROBABLE MINIMUM SPECIFIC ENERGY
1
    3/22/91       0:48:40                                                                  PAGE    6


   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS   BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA   LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST


 3720 CRITICAL DEPTH ASSUMED
    10.00     6.35  1343.05  1343.05      .00  1345.18     2.13      .72      .11  1338.80
    2650.       0.    2141.     509.       0.     168.      90.       2.       1.   1338.60
      .01      .66    12.75     5.62     .045     .035     .055     .000  1336.70    83.81
  .009309      80.      80.      80.       20       11        0      .00    62.80   146.61
0
 FLOW DISTRIBUTION FOR SECNO=     10.00          CWSEL=   1343.05

 STA=      84.      84.     114.     120.     121.     130.     144.     147.
   PER Q=       .0     80.8      5.3       .8      8.6      4.4       .0
    AREA=       .4    168.0     21.6      3.8     36.1     28.4       .5
     VEL=       .7     12.7      6.5      5.9      6.3      4.1      1.0
   DEPTH=      2.1      5.6      4.0      3.8      3.8      2.0       .2
```

THIS RUN EXECUTED 3/22/91 0:48:42

****
HEC2 RELEASE DATED SEPT 88

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NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

TING UPSTREAM CHANNEL (Q

SUMMARY PRINTOUT TABLE 150

	SECNO	XLCH	ELTRD	ELLC	ELMIN	Q	CWSEL	CRIWS	EG	10*KS	VCH	AREA	.01K
*	5.090	.00	.00	.00	1346.50	2650.00	1352.91	1352.91	1355.16	93.33	12.25	236.66	274.30
	6.000	.00	.00	.00	1343.90	2650.00	1351.01	1351.98	1354.99	162.70	16.54	177.94	207.76
	6.730	91.00	.00	.00	1342.70	2650.00	1349.77	1350.87	1353.60	134.26	16.62	202.42	228.71
*	7.700	70.00	.00	.00	1339.90	2650.00	1346.13	1348.18	1351.93	268.02	20.09	153.08	161.87
	8.700	100.00	.00	.00	1338.40	2650.00	1343.80	1345.30	1348.50	335.84	17.62	158.78	144.60
*	9.500	100.00	.00	.00	1337.00	2650.00	1344.18	1344.18	1345.96	87.71	11.24	286.39	282.96
*	10.000	80.00	.00	.00	1336.70	2650.00	1343.05	1343.05	1345.18	93.09	12.75	258.85	274.66

TING UPSTREAM CHANNEL (Q

SUMMARY PRINTOUT TABLE 150

	SECNO	Q	CWSEL	DIFWSP	DIFWSX	DIFKWS	TOPWID	XLCH
*	5.090	2650.00	1352.91	.00	.00	4.41	60.35	.00
	6.000	2650.00	1351.01	.00	-1.90	.00	39.70	.00
	6.730	2650.00	1349.77	.00	-1.24	.00	60.36	91.00
*	7.700	2650.00	1346.13	.00	-3.64	.00	47.45	70.00
	8.700	2650.00	1343.80	.00	-2.33	.00	52.51	100.00
*	9.500	2650.00	1344.18	.00	.39	.00	97.84	100.00
*	10.000	2650.00	1343.05	.00	-1.13	.00	62.80	80.00

SUMMARY OF ERRORS AND SPECIAL NOTES

CAUTION SECNO=	5.090	PROFILE=	1	CRITICAL DEPTH ASSUMED
WARNING SECNO=	7.700	PROFILE=	1	CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
CAUTION SECNO=	9.500	PROFILE=	1	CRITICAL DEPTH ASSUMED
CAUTION SECNO=	9.500	PROFILE=	1	PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO=	9.500	PROFILE=	1	20 TRIALS ATTEMPTED TO BALANCE WSEL
CAUTION SECNO=	10.000	PROFILE=	1	CRITICAL DEPTH ASSUMED
CAUTION SECNO=	10.000	PROFILE=	1	PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO=	10.000	PROFILE=	1	20 TRIALS ATTEMPTED TO BALANCE WSEL

```
1*****************************************************
*  WATER SURFACE PROFILES                            *
*  VERSION OF SEPTEMBER 1988                         *
*  ERROR: 01                                         *
*  UPDATED: 16 FEBRUARY 1989                         *
*  RUN DATE    3/26/91   TIME   12:23:59             *
*****************************************************
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****************************************
*  U.S. ARMY CORPS OF ENGINEERS        *
*  THE HYDROLOGIC ENGINEERING CENTER   *
*  609 SECOND STREET, SUITE D          *
*  DAVIS, CALIFORNIA 95616             *
*  (916) 756-1104                      *
****************************************
```

REVISED UPSTREAM REACH

```
X     X  XXXXXXX   XXXXX              XXXXX
X     X  X        X     X            X     X
X     X  X        X                        X
XXXXXXX  XXXX     X          XXXXX    XXXXX
X     X  X        X                  X
X     X  X        X     X            X
X     X  XXXXXXX   XXXXX             XXXXXXX
```

END OF BANNER

1

3/26/91 12:23:59 PAGE 1

THIS RUN EXECUTED 3/26/91 12:23:59

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**************************************************
  HEC2 RELEASE DATED SEPT 88

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T1 BUSH HWY BOX CULVERT - UPSTREAM SECTIONS (BHCHNU.DAT/OUT)
T2 INCA ENGINEERS/FCDMC 90-46/AGK JOB NO. 425.40
T3 NEW UPSTREAM CHANNEL (Q=2650 CFS)

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	0	0	0	1	-1	0	0	2650.	1348.5	0

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1	0	-1	0	0	0	-1	0	0	15

NC	.045	.055	.035	.1	.3					
X1	5.09	8.0	84.9	124.9						
GR	1367.0	54.6	1352.2	75.0	1352.5	81.7	1348.0	84.9	1346.5	100.0
GR	1349.5	124.9	1363.6	164.0	1365.2	176.6				
X1	6.00	14.0	82.7	109.3	91.0	91.0	91.0			
GR	1376.2	33.6	1365.1	61.5	1349.9	76.4	1345.4	82.7	1343.9	89.3
GR	1345.7	102.0	1347.4	103.8	1347.9	109.3	1351.6	116.1	1352.2	120.4
GR	1356.8	133.3	1359.1	143.7	1358.8	157.9	1360.9	173.2		
X1	6.73	13.0	92.7	115.0	80.0	55.0	70.0			
GR	1368.3	39.3	1363.9	56.3	1355.5	78.0	1344.2	92.7	1343.2	100.0
GR	1342.7	107.0	1344.1	110.8	1343.9	115.0	1347.8	119.3	1349.3	128.1
GR	1348.6	143.6	1353.8	153.4	1357.7	181.9				
NC				.2	.4					
X1	7.70	16.0	84.4	108.5	100.0	100.0	100.0			

```
GR   1363.0     37.8    1349.5     51.0    1346.3     64.4    1345.5     76.0    1343.3     83.0
GR   1341.8     84.4    1339.9     94.2    1341.8    101.3    1341.8    108.5    1347.1    115.5
GR   1346.6    134.9    1353.5    150.7    1353.8    160.4    1350.6    179.7    1357.1    195.2
GR   1359.3    210.3

X1     8.70     11.0      68.0    120.0     100.0    100.0     100.0
GR   1353.8     40.1    1346.1     56.0    1346.0     68.0    1340.0     80.0    1340.0    100.0
GR   1339.7    108.7    1338.4    112.1    1339.5    119.2    1341.0    120.0    1350.1    140.3
GR   1352.4    155.1

X1     9.50     15.0      60.9    123.9      80.0     80.0      80.0
X3       10
GR   1350.4     60.9    1343.0     71.0    1339.0     71.1    1339.0     80.0    1339.0     91.0
GR   1338.8     96.9    1337.9    103.9    1337.0    106.1    1338.1    110.3    1338.7    115.8
GR   1343.5    123.9    1345.0    136.5    1342.0    168.0    1342.2    179.3    1355.4    221.1
```



```
SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

*PROF 1

CRITICAL DEPTH TO BE CALCULATED AT ALL CROSS SECTIONS
0

CCHV=     .100 CEHV=     .300
*SECNO 5.090
3720 CRITICAL DEPTH ASSUMED
    5.09     6.41  1352.91  1352.91  1348.50  1355.16     2.25      .00      .00  1348.00
   2650.      45.    2547.      58.      13.     208.      16.       0.       0.  1349.50
     .00     3.56    12.25     3.58     .045     .035     .055     .000  1346.50    74.02
 .009333       0.       0.       0.        0       22        0      .00    60.35   134.37
0
FLOW DISTRIBUTION FOR SECNO=      5.09          CWSEL=   1352.91

STA=      74.      75.      82.      85.     125.     134.
  PER Q=      .0       .3      1.4     96.1      2.2
   AREA=      .4      3.8      8.5    207.9     16.2
    VEL=     1.4      2.2      4.3     12.3      3.6
  DEPTH=      .4       .6      2.7      5.2      1.7

*SECNO 6.000

3301 HV CHANGED MORE THAN HVINS

    6.00     7.11  1351.01  1351.98      .00  1354.99     3.98      .00      .17  1345.40
   2650.     176.    2437.      38.      22.     147.       9.       0.       0.  1347.90
     .00     8.07    16.54     4.24     .045     .035     .055     .000  1343.90    75.31
 .016270       0.       0.       0.        7       11        0      .00    39.70   115.01
0
FLOW DISTRIBUTION FOR SECNO=      6.00          CWSEL=   1351.01

STA=      75.      76.      83.     109.     115.
  PER Q=      .1      6.6     92.0      1.4
```

```
  AREA=      .6     21.2    147.3      8.9
   VEL=     2.2      8.2     16.5      4.2
 DEPTH=      .6      3.4      5.5      1.6
```



```
  SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
  Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
  TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
  SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

*SECNO 6.730
    6.73     7.07  1349.77  1350.87      .00  1353.60     3.83     1.34      .04  1344.20
   2650.     131.    2336.     183.      20.     141.      42.       0.       0.  1343.90
     .00     6.49    16.62     4.40     .045     .035     .055     .000  1342.70    85.45
 .013426      91.      91.      91.        8        8        0      .00    60.36   145.81
0
FLOW DISTRIBUTION FOR SECNO=      6.73          CWSEL=   1349.77

STA=      85.      93.     115.     119.     128.     144.     146.
  PER Q=     4.9     88.1      4.1      1.4      1.3       .1
   AREA=    20.2    140.5     16.9     10.8     12.7      1.3
    VEL=     6.5     16.6      6.4      3.5      2.7      2.0
  DEPTH=     2.8      6.3      3.9      1.2       .8       .6

CCHV=     .200 CEHV=     .400
*SECNO 7.700

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE

    7.70     6.23  1346.13  1348.18      .00  1351.93     5.80     1.28      .39  1341.80
   2650.     149.    2422.      79.      20.     121.      12.       1.       0.  1341.80
     .00     7.39    20.09     6.37     .045     .035     .055     .000  1339.90    66.78
 .026802      80.      70.      55.        9        8        0      .00    47.45   114.23
0
FLOW DISTRIBUTION FOR SECNO=      7.70          CWSEL=   1346.13

STA=      67.      76.      83.      84.     109.     114.
  PER Q=      .3      3.5      1.9     91.4      3.0
   AREA=     2.9     12.2      5.0    120.6     12.4
    VEL=     2.5      7.6      9.8     20.1      6.4
  DEPTH=      .3      1.7      3.6      5.0      2.2

*SECNO 8.700

3301 HV CHANGED MORE THAN HVINS
```



```
  SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
  Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
  TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
  SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST


    8.70     4.62  1343.02  1344.64      .00  1348.31     5.29     3.42      .20  1346.00
   2650.       0.    2625.      25.       0.     142.       5.       1.       0.  1341.00
     .00      .00    18.54     5.43     .000     .035     .055     .000  1338.40    73.96
```

```
 .045026     100.     100.     100.        5        5        0      .00    50.54   124.50

FLOW DISTRIBUTION FOR SECNO=      8.70          CWSEL=   1343.02

STA=      74.     120.     125.
  PER Q=     99.1       .9
   AREA=    141.6      4.5
    VEL=     18.5      5.4
  DEPTH=      3.1      1.0

*SECNO 9.500

3301 HV CHANGED MORE THAN HVINS

3685 20 TRIALS ATTEMPTED WSEL,CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=      1350.40 ELREA=      1343.50

     9.50     6.10  1343.10  1343.10      .00  1345.40     2.29     2.31     2.10  1350.40
    2650.       0.    2650.       0.       0.     218.       0.       1.       0.   1343.50
      .01      .00    12.16      .00     .000     .035     .000     .000  1337.00    70.86
  .014005     100.     100.     100.       20       14        0      .00    52.37   123.23

FLOW DISTRIBUTION FOR SECNO=      9.50          CWSEL=   1343.10

STA=      71.     124.
  PER Q=    100.0
   AREA=    218.0
    VEL=     12.2
  DEPTH=      4.2
```


THIS RUN EXECUTED 3/26/91 12:24:17

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****************************************************
  HEC2 RELEASE DATED SEPT 88

****************************************************

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

UPSTREAM CHANNEL      (Q

SUMMARY PRINTOUT TABLE  150
```

	SECNO	XLCH	ELTRD	ELLC	ELMIN	Q	CWSEL	CRIWS	EG	10*KS	VCH	AREA	.01K
*	5.090	.00	.00	.00	1346.50	2650.00	1352.91	1352.91	1355.16	93.33	12.25	236.66	274.30
	6.000	.00	.00	.00	1343.90	2650.00	1351.01	1351.98	1354.99	162.70	16.54	177.94	207.76
	6.730	91.00	.00	.00	1342.70	2650.00	1349.77	1350.87	1353.60	134.26	16.62	202.42	228.71
*	7.700	70.00	.00	.00	1339.90	2650.00	1346.13	1348.18	1351.93	268.02	20.09	153.08	161.87
	8.700	100.00	.00	.00	1338.40	2650.00	1343.02	1344.64	1348.31	450.26	18.54	146.16	124.89

*	9.500	100.00	.00	.00	1337.00	2650.00	1343.10	1343.10	1345.40	140.05	12.16	217.99	223.92

UPSTREAM CHANNEL (Q

SUMMARY PRINTOUT TABLE 150

	SECNO	Q	CWSEL	DIFWSP	DIFWSX	DIFKWS	TOPWID	XLCH
*	5.090	2650.00	1352.91	.00	.00	4.41	60.35	.00
	6.000	2650.00	1351.01	.00	-1.90	.00	39.70	.00
	6.730	2650.00	1349.77	.00	-1.24	.00	60.36	91.00
*	7.700	2650.00	1346.13	.00	-3.64	.00	47.45	70.00
	8.700	2650.00	1343.02	.00	-3.11	.00	50.54	100.00
*	9.500	2650.00	1343.10	.00	.09	.00	52.37	100.00

SUMMARY OF ERRORS AND SPECIAL NOTES

CAUTION SECNO= 5.090 PROFILE= 1 CRITICAL DEPTH ASSUMED

WARNING SECNO= 7.700 PROFILE= 1 CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

CAUTION SECNO= 9.500 PROFILE= 1 CRITICAL DEPTH ASSUMED
CAUTION SECNO= 9.500 PROFILE= 1 PROBABLE MINIMUM SPECIFIC ENERGY
CAUTION SECNO= 9.500 PROFILE= 1 20 TRIALS ATTEMPTED TO BALANCE WSEL

```
1*******************************************************
 *  WATER SURFACE PROFILES                             *
 *  VERSION OF SEPTEMBER 1988                          *
 *  ERROR: 01                                          *
 *  UPDATED: 16 FEBRUARY 1989                          *
 *  RUN DATE     3/22/91    TIME    15:52:38           *
*******************************************************
```

```
****************************************
*  U.S. ARMY CORPS OF ENGINEERS        *
*  THE HYDROLOGIC ENGINEERING CENTER   *
*  609 SECOND STREET, SUITE D          *
*  DAVIS, CALIFORNIA 95616             *
*  (916) 756-1104                      *
****************************************
```

EXISTING DOWNSTREAM REACH

```
X     X  XXXXXXX   XXXXX              XXXXX
X     X  X        X     X            X     X
X     X  X        X                        X
XXXXXXX  XXXX     X          XXXXX    XXXXX
X     X  X        X                  X
X     X  X        X     X            X
X     X  XXXXXXX   XXXXX              XXXXXXX
```

END OF BANNER

3/22/91 15:52:38 PAGE 1

THIS RUN EXECUTED 3/22/91 15:52:38

```
*************************************************
 HEC2 RELEASE DATED SEPT 88

*************************************************
```

T1 BUSH HWY BOX CULVERT - DOWNSTREAM SECTIONS (BHBCDN.DAT/OUT)
T2 INCA ENGINEERS/FCDMC 90-46/AGK JOB NO. 425.40
T3 EXISTING DOWNSTREAM CHANNEL (Q=2650 CFS)

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	0	0	0	1	-1	0	0	2650.	1333.	0

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	-1	0	-1	0	0	0	-1	0	0	15

NC	0.035	0.035	0.030	0.1	0.3					
X1	11.50	10.0	58.8	130.3						
GR	1338.8	58.8	1330.9	73.4	1330.3	77.4	1330.8	83.8	1330.5	93.6
GR	1329.8	100.0	1329.6	105.3	1330.6	109.4	1330.7	115.3	1342.0	130.3
X1	12.16	9.0	57.7	145.7	66.0	66.0	66.0			
GR	1336.7	57.7	1329.3	64.6	1329.4	107.5	1328.7	110.8	1327.6	113.1
GR	1328.5	119.7	1329.7	123.0	1330.1	125.4	1340.3	145.7		
X1	13.0	10.0	60.2	134.2	84.0	84.0	84.0			
GR	1335.6	60.2	1326.9	71.9	1326.6	78.6	1327.3	81.0	1327.5	86.9
GR	1328.1	89.6	1327.8	100.0	1327.4	114.7	1327.8	118.5	1338.5	134.2
X1	13.60	9.0	51.9	128.0	60.0	60.0	60.0			
GR	1333.1	51.9	1326.9	59.9	1325.3	65.1	1325.5	69.7	1326.5	71.7
GR	1326.9	81.0	1326.8	100.0	1326.7	114.3	1336.6	128.0		

```
X1    15.34      10.0      42.0     132.0     174.0     174.0     174.0
GR   1330.2      42.0    1324.3      48.3    1323.6      51.2    1323.7      62.0    1324.1      63.7
GR   1323.9      81.0    1323.6      86.5    1324.0      91.2    1323.9     114.4    1331.8     132.0
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST

*PROF 1

CRITICAL DEPTH TO BE CALCULATED AT ALL CROSS SECTIONS
0

CCHV=     .100 CEHV=     .300
*SECNO 11.500
3720 CRITICAL DEPTH ASSUMED
    11.50     5.53  1335.13  1335.13  1333.00  1337.22     2.09      .00      .00  1338.80
    2650.       0.    2650.       0.       0.     229.       0.       0.       0.  1342.00
      .00      .00    11.59      .00     .000     .030     .000     .000  1329.60    65.58
  .008877       0.       0.       0.        0       13        0      .00    55.60   121.18

FLOW DISTRIBUTION FOR SECNO=     11.50          CWSEL=   1335.13

STA=      66.     130.
  PER Q=    100.0
   AREA=    228.6
    VEL=     11.6
  DEPTH=      4.1

*SECNO 12.160

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE

    12.16     3.82  1331.42  1332.99      .00  1336.88     5.46      .00      .34  1336.70
    2650.       0.    2650.       0.       0.     141.       0.       0.       0.  1340.30
      .00      .00    18.76      .00     .000     .030     .000     .000  1327.60    62.63
  .053303       0.       0.       0.        9        8        0      .00    65.39   128.02

FLOW DISTRIBUTION FOR SECNO=     12.16          CWSEL=   1331.42

STA=      63.     146.
  PER Q=    100.0
   AREA=    141.3
    VEL=     18.8
  DEPTH=      2.2

1
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST
```

```
*SECNO 13.000

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE

    13.00     4.45  1331.05  1331.91      .00  1334.26     3.21     1.94      .68  1335.60
    2650.       0.    2650.       0.       0.     184.       0.       0.       0.  1338.50
      .00      .00    14.37      .00     .000     .030     .000     .000  1326.60    66.32
  .018643      66.      66.      66.        7       11        0      .00    56.95   123.27

FLOW DISTRIBUTION FOR SECNO=     13.00          CWSEL=   1331.05

STA=      66.     134.
  PER Q=    100.0
   AREA=    184.4
    VEL=     14.4
  DEPTH=      3.2

*SECNO 13.600

3301 HV CHANGED MORE THAN HVINS

    13.60     4.76  1330.06  1330.62      .00  1332.67     2.62     1.41      .18  1333.10
    2650.       0.    2650.       0.       0.     204.       0.       1.       0.  1336.60
      .00      .00    12.98      .00     .000     .030     .000     .000  1325.30    55.82
  .015178      84.      84.      84.        5       11        0      .00    63.13   118.95

FLOW DISTRIBUTION FOR SECNO=     13.60          CWSEL=   1330.06

STA=      56.     128.
  PER Q=    100.0
   AREA=    204.1
    VEL=     13.0
  DEPTH=      3.2

*SECNO 15.340
```



```
   SECNO    DEPTH    CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    BANK ELEV
   Q        QLOB     QCH      QROB     ALOB     ACH      AROB     VOL      TWA    LEFT/RIGHT
   TIME     VLOB     VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN      SSTA
   SLOPE    XLOBL    XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID     ENDST


3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE

    15.34     2.45  1326.05  1327.46      .00  1330.93     4.88     1.52      .23  1330.20
    2650.       0.    2650.       0.       0.     149.       0.       1.       0.  1331.80
      .00      .00    17.73      .00     .000     .030     .000     .000  1323.60    46.44
  .050251      60.      60.      60.        7       15        0      .00    72.74   119.18

FLOW DISTRIBUTION FOR SECNO=     15.34          CWSEL=   1326.05

STA=      46.     132.
  PER Q=    100.0
   AREA=    149.4
    VEL=     17.7
```

DEPTH= 2.1

THIS RUN EXECUTED 3/22/91 15:52:51

****
HEC2 RELEASE DATED SEPT 88

****

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

TING DOWNSTREAM CHANNEL

SUMMARY PRINTOUT TABLE 150

	SECNO	XLCH	ELTRD	ELLC	ELMIN	Q	CWSEL	CRIWS	EG	10*KS	VCH	AREA	.01K
*	11.500	.00	.00	.00	1329.60	2650.00	1335.13	1335.13	1337.22	88.77	11.59	228.57	281.26
*	12.160	.00	.00	.00	1327.60	2650.00	1331.42	1332.99	1336.88	533.03	18.76	141.27	114.78
*	13.000	66.00	.00	.00	1326.60	2650.00	1331.05	1331.91	1334.26	186.43	14.37	184.40	194.09
	13.600	84.00	.00	.00	1325.30	2650.00	1330.06	1330.62	1332.67	151.78	12.98	204.13	215.10
*	15.340	60.00	.00	.00	1323.60	2650.00	1326.05	1327.46	1330.93	502.51	17.73	149.44	118.22

TING DOWNSTREAM CHANNEL

SUMMARY PRINTOUT TABLE 150

	SECNO	Q	CWSEL	DIFWSP	DIFWSX	DIFKWS	TOPWID	XLCH
*	11.500	2650.00	1335.13	.00	.00	2.13	55.60	.00
*	12.160	2650.00	1331.42	.00	-3.71	.00	65.39	.00
*	13.000	2650.00	1331.05	.00	-.36	.00	56.95	66.00
	13.600	2650.00	1330.06	.00	-1.00	.00	63.13	84.00
*	15.340	2650.00	1326.05	.00	-4.01	.00	72.74	60.00

SUMMARY OF ERRORS AND SPECIAL NOTES

```
CAUTION SECNO=     11.500  PROFILE=  1  CRITICAL DEPTH ASSUMED

WARNING SECNO=     12.160  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=     13.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=     15.340  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

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SHEET _____ OF _____
BY SEK DATE 3/91
CHECK _____ DATE _____
CLIENT INCA / FCDMC
JOB Bush Hwy Box Culvert JOB NO. 425.40

RIPRAP DESIGN

1. Standard Stone Size

According to MAG Std. Spec. 703.2, at least 50% of stone shall weigh not less than 100 pounds and the minimum weigh shall be 10 pounds. Thus,

$$W_{50} = 100 \text{ lbs.}$$

$$\text{and} \quad W_{min} = 10 \text{ lbs.}$$

Relation between stone size and weight:

$$D_s = \left(\frac{6W}{\pi \gamma_s}\right)^{1/3} = 1.24\left(\frac{W}{\gamma_s}\right)^{1/3}$$

Where D_s = Stone diameter in ft
W = Stone weight in lbs
γ_s = Specific weight of ston in pcf

Assuming $\gamma_s = 165$ pcf

$$D_{50} = 1.24\left(\frac{100}{165}\right)^{1/3} = 1.05' = 12.6''$$

$$D_{min} = 1.24\left(\frac{10}{165}\right)^{1/3} = 0.49' \cong 6''$$

Therefore, according to MAG Std. Spec. 703.2,

$D_{50} = 12.6''$ and $D_{min} = 6''$

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JOB Bush Hwy Box Culvert JOB NO. 425.40

2. Riprap Size Along Embankment

According to FHWA, the size of stone needed to protect a streambed or highway embankment from erosion by a current moving parallel to the embankment can be determined by the velocity method.

Based on results from HEC-2 analysis, the highest velocity of flow within the project limits occurs at Sta. 8+00.

At Sta. 8+70, $V = 18.54$ fps, Depth $= 4.62'$

At Sta. 7+70, $V = 20.09$ fps, Depth $= 6.23'$

Thus, at Sta. 8+00 $V = 19.6$ fps, Depth $= 5.75'$

The suitability of stone size as specified in MAG Std. Spec. 703.2 is checked by the following steps:

a. Assuming $D_{50} = 12.6'' = 1.05'$

b. Flow Depth $y = 5.75'$

c. $D_{50}/y = 1.05'/5.75' = 0.183$

d. From Figure A, velocity against stone, $V_s = 0.59 \times 19.6$
$= 11.6$ fps

e. From Figure B, required $D_{50} = 1.15' = 13.8''$

f. The required size of D_{50} is slightly greater than MAG Std. D_{50} size, thus use grouted riprap to increase the resistance.

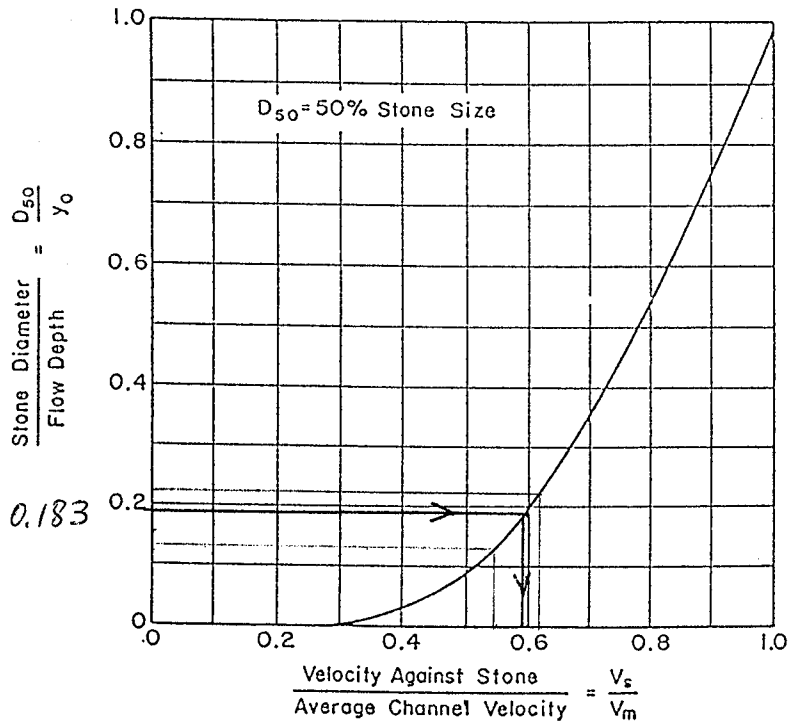

Figure A. Velocity against stone on channel bottom (From HEC 11, U. S. DOT, 1967).

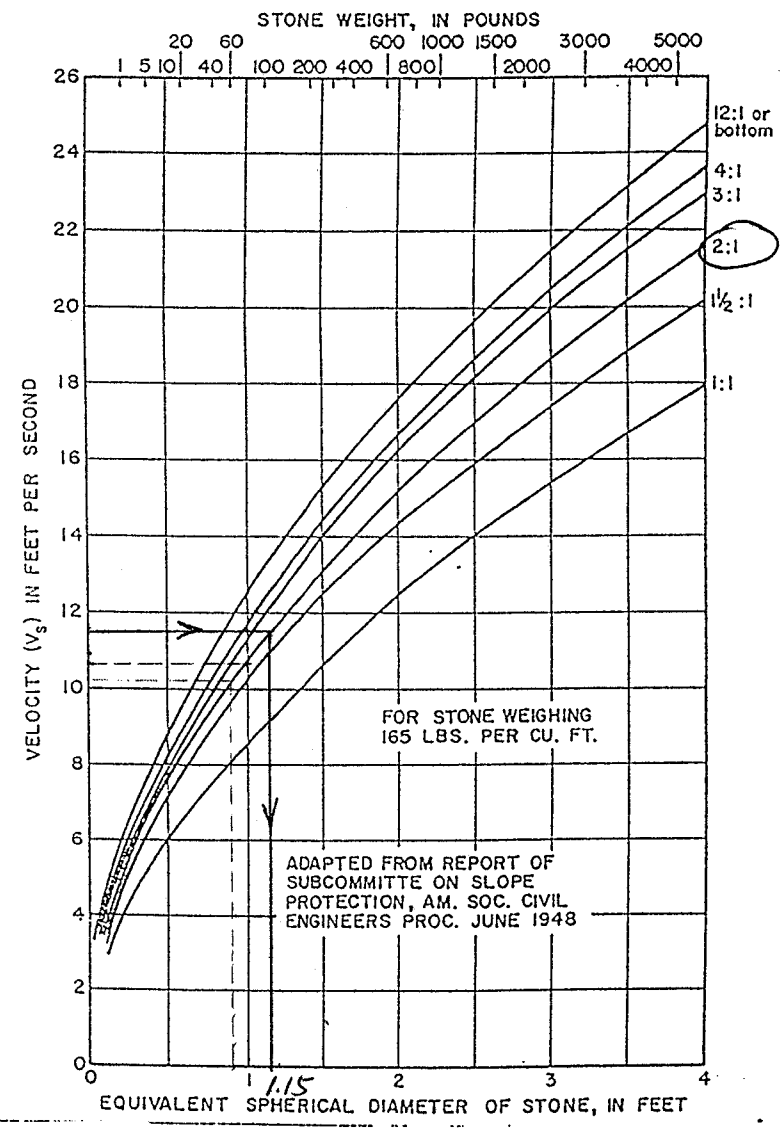

Figure B. Size of stone that will resist displacement for various velocities and side slopes. (From Hec 11, 1967).

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JOB Bush Hwy Box Culvert JOB NO. 425.40

Check of suitability for MAG Std. D_{50} size at Sta. 8+50:

a. $D_{50} = 12.6'' = 1.05'$

b. Flow Depth @ Sta. 8+50 = 4.94'

c. Flow Velocity @ Sta. 8+50 = 18.85 fps

d. $D_{50}/y = 1.05'/4.94' = 0.22$

e. From Fig. A, $V_s/V_m = 0.62$

f. Velocity against stone $V_s = 0.62 \times 18.85 = 11.7$ fps

g. From Fig. B, required $D_{50} = 12'' < 12.6''$ OK.

Therefore, MAG Std. size of D_{50} is suitable for this project.

3. <u>Riprap Size at Culvert North Inlet</u>

There is a sharp change of stream alignment at the culvert inlet. The California Highway Division recommends doubling the velocity against the stone as determined for straight alignment before entering Fig. B for stone size.

The entrance velocity of the culvert $V = 9.46$ fps.

The flow depth at the inlet $y = 8.4'$

$D_{50}/y = 1.05'/8.4' = 0.125$

From Fig. A, $V_s = 0.54 \times 9.46 = 5.1$ fps

Double $V_s = 2 \times 5.1$ fps $= 10.2$ fps

From Fig. B, required $D_{50} = 0.9' = 10.8'' < 12.6''$ OK

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SHEET _____ OF _____
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CLIENT _____
JOB Bush Hwy Box Culvert JOB NO. 425.40

4. Riprap Gradation and Thickness

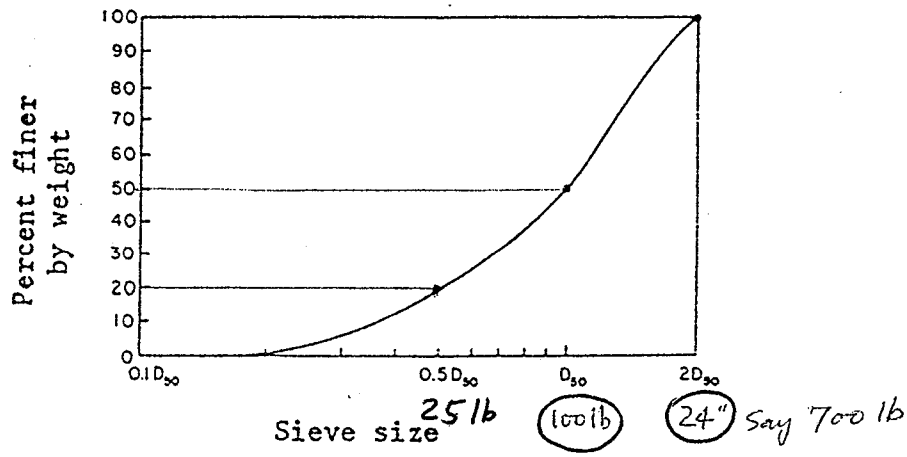

Fig. 5.2.10 Suggested gradation for riprap.

Assume: Riprap Thickness = D_{Max}.

Sphere Volume $= \frac{1}{6}\pi d^3 = 0.5236\, d^3$

Weight of Stone = 165 #/C.F.

Stone Size (in)	Volume (C.F.)	Weight (#)
6"	0.065	10.8
→ 8"	0.155	25.6
10"	0.303	50.0
12"	0.524	86
16"	1.24	205
20"	2.42	400
→ 24"	4.19	691
30"	8.18	1350
36"	14.14	2333

Use

1. $D_{Min} \cong 8''$ or 25 lbs.
2. $D_{50} \cong 12.6''$ or 100 lbs.
3. $D_{Max} \cong 2 \times D_{50} \cong 24''$ or 700 lbs.

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TO: INCA/J. Lynck

FROM: S.E. Kao

JOB: Bush Highway Box Culvert

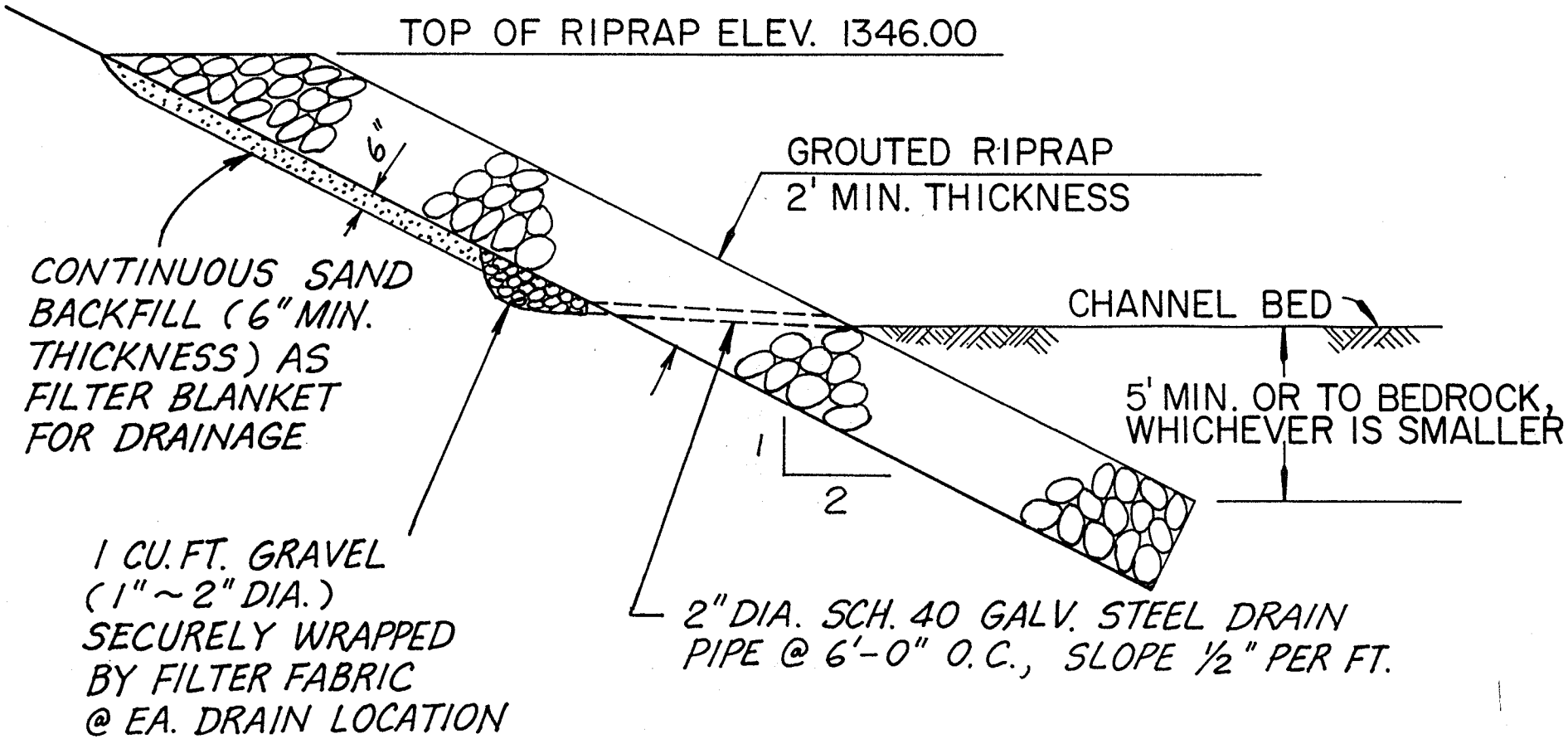
JOB NO.: 425.40

DATE: July 15, 1991

MEMORANDUM

Transmitted herewith is a sketch showing the typical section of grouted riprap. This sketch reflects our response to FCDMC's comment that we received through the telephone conversation with you on July 11, 1991.

Please note that a weep hole should be placed along the grouted riprap embankment at an interval of 6 feet. The weep hole consists of a 2" diameter galvanized steel pipe (Schedule 40), with a laying slope of 1/2" per foot. A continuous layer of sand, with a minimum thickness of 6 inches, should be placed under the grouted riprap (as shown on the sketch) to provide a layer of filter blanket for drainage. One cubic foot of gravel (1" to 2" in diameter), securely wrapped by filter fabric, should be placed at each weep hole location.



TYPICAL SECTION OF GROUTED RIPRAP

ACK ENGINEERS, INC.
2255 N. 44th St. Phoenix, Az. 85008 • Phone (602) 244-2566

TO: File/INCA

FROM: S.E. Kao

JOB: Bush Highway Box Culvert

JOB NO.: 425.40

DATE: May 28, 1991

MEMORANDUM

SCOUR ANALYSIS

Scour can usually be classified as general scour and local scour. General scour is provoked by the imbalance in sediment transport resulting from a continuous change of river bed elevation with time. local scour refers to scour caused by local obstructions such as bridge piers, abutments, and bends.

The Bush Highway box culvert acts as a grade control structure and the stream bed immediately upstream of the box culvert is not expected to be lowered by long-term degradation process. Therefore, general scour does not need to be considered in this study.

The scour depths to be caused by local scour near the box culvert are discussed as follows:

1. **Scour at Culvert Entrance**

   To our best knowledge, there is no known formula for estimation of scour depth at culvert entrance. In this study, the empirical formula for scour depth prediction at bridge piers, as developed by Colorado State University (CSU) and reported in the Federal Highway Administration Manual, was "borrowed" to estimate the scour depth at the culvert entrance.

   Based on the given hydraulic characteristics, the potential scour depth at the culvert entrance was estimated to be 3.7 feet. Therefore, we recommend that the standard ADOT cut-off wall depth of four feet be used in this project.

2. **Scour at the Bend**

   The scour depth at the bend near the culvert entrance was estimated by use of the formula developed by Zeller (Reference 2). As shown on the attached calculation sheets, the scour depth due to the bend was estimated to be 0.8 foot. Therefore, the total depth of scour potential for the curved embankment near the culvert entrance is equal to 3.7' + 0.8' = 4.5 feet.

   Based on this estimated scour depth, we recommend that the toe-down depth for the rip rap be 5 feet below the stream bed.

REFERENCES

1. H.H. Chang, *Fluvial Processes in River Engineering*, John Wiley & Sons, 1988.

2. Arizona Transportation Research Center, *Engineering Analysis of Fluvial Systems*, Arizona Department of Transportation, July 1986.

3. Arizona Department of Transportation, *Drainage Manual, Volume 1, Policy*, August 1987.

1. SCOUR AT CULVERT

According to the Colorado State Univ. (CSU) Equation:

$$\frac{D_s}{D_o} = 2.2\left(\frac{b}{D_o}\right)^{0.65}(\mathbb{F}_o)^{0.43}$$

where D_s = depth of scour below mean bed elevation (ft)

D_o = mean depth of flow upstream of pier (ft)

b = pier width (ft)

$\mathbb{F}_o$ = Froud number based on mean stream velocity U_o and depth D_o

a. Entrance Velocity at Culvert $U_o = 9.46$ fps

b. Flow Depth at the Culvert Inlet $D_o = 8.4'$

c. Pier Width $b = 1'$

d. $\mathbb{F}_o = \dfrac{U_o}{\sqrt{32 D_o}} = \dfrac{9.46}{\sqrt{32 \times 8.4}} = 0.58$

e. $D_s = D_o \times 2.2\left(\dfrac{b}{D_o}\right)^{0.65}(\mathbb{F}_o)^{0.43}$

$= 2.2 \times 8.4 \times \left(\dfrac{1}{8.4}\right)^{0.65}(0.58)^{0.43}$

$= 2.2 \times 8.4 \times 0.25 \times 0.79$

$= 3.7'$

f. ADOT Std. Cut-off Wall for Box Culvert $= 4.0' > 3.7'$

2. SCOUR AT BEND

According to Zeller's Formula (1981):

$$Z = \frac{0.0685\, D_o U_o^{0.8}}{y^{0.4}\, S_e^{0.3}} \left[2.1 \left(\frac{\sin^2 \frac{\alpha}{2}}{\cos \alpha} \right)^{0.2} - 1 \right]$$

where Z = scour depth

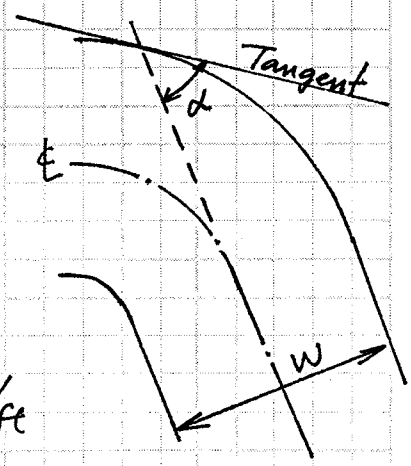
D_o = depth of flow (ft)

y = hydraulic depth of upstream flow (ft)

U_o = mean stream velocity (fps)

S_e = upstream energy slope (ft/ft)

α = angle formed by curvature



At the bend near culvert entrance:

a. $D_o = 8.4'$

b. $y \cong D_o = 8.4'$

c. $U_o = 9.46$ fps

d. $S_e = \frac{1348.31 - 1345.4}{80} = 0.0364$ ft/ft

e. $\alpha = 27°$

f. $$Z = \frac{0.0685 \times 8.4 \times 9.46^{0.8}}{(8.4)^{0.4} \times (0.0364)^{0.3}} \left[2.1 \left(\frac{\sin^2 13.5°}{\cos 27°} \right)^{0.2} - 1 \right]$$

$$= \frac{0.0685 \times 8.4 \times 6.035}{2.342 \times 0.370} (0.20) = 0.8'$$

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BY SEK DATE 5/91

CHECK _____ DATE _____

CLIENT FCDMC / INCA

JOB Bush Hwy Box Culvert JOB NO. 425.40

3. RECOMMENDATIONS

a. For cut-off wall depth at the box culvert, use 4'.

b. For riprap toe-down depth, use 5'
because total scour potential = 3.7' + 0.8' = 4.5'