US Army Corps of Engineers

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-91-23

# PERRY CREEK CONDUIT SIOUX CITY, IOWA

## Hydraulic Model Investigation

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

December 1991

Final Report



Prepared for US Army Engineer District, Omaha
Omaha, Nebraska 68102-4978

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
December 1991

**3. REPORT TYPE AND DATES COVERED**
Final report

**4. TITLE AND SUBTITLE**
Perry Creek Conduit, Sioux City, Iowa;
Hydraulic Model Investigation

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
Hite, John E., Jr.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
USAE Waterways Experiment Station, Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

**8. PERFORMING ORGANIZATION REPORT NUMBER**
Technical Report HL-91-23

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
US Army Engineer District, Omaha,
Omaha, NB 68102-4978

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

A model investigation was conducted to evaluate the performance of a proposed improvement plan and develop modifications, if needed, that would enable the Perry Creek Conduit to safely pass a 16,000-cfs discharge. Model tests revealed that the capacity of the original design flood control channel was only 10,200 cfs and excessive bend losses were occurring. A second improvement plan was designed and tested in the model and found to be satisfactory provided modifications are made to the channel berms and channel invert and a stilling basin is installed at the end of the conduit. Discharge and velocity measurements and water-surface elevations are presented and flow conditions are shown in photographs.

**14. SUBJECT TERMS**

| | |
|---|---|
| Channel improvement | Hydraulic models |
| Flood-control channels | Perry Creek, Sioux City, Iowa |

**15. NUMBER OF PAGES**
54

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | |

# PREFACE

The investigation reported herein was authorized by Headquarters, US Army Corps of Engineers, on 7 November 1986, at the request of the US Army Engineer District, Omaha (MRO). The studies were conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during July 1987 to September 1989 under the direction of Messrs. Frank A. Herrmann, Jr., Chief, HL, and Glenn A. Pickering, Chief, Hydraulic Structures Division. The tests were conducted by Messrs. Thomas E. Murphy, Jr., and John E. Hite, Jr., of the Locks and Conduits Branch under the supervision of Mr. John F. George, Chief, Locks and Conduits Branch. This report was prepared by Mr. Hite.

The model was constructed by the late Mr. Ernest B. Williams and Messrs. Ed Case and Joe Lyons of the Engineering and Construction Services Division under the supervision of Mr. Sidney J. Leist, Chief of the Model Shop, Engineering and Construction Services Division.

Prior to design and construction of the model, Messrs. Pickering and Hite visited the project site to inspect the existing conduit. Messrs. Al Harrison, Warren Mellema, Al Swoboda, and Tsong Wei of the Missouri River Division and Ed Sizemore, Frank Vovk, Tim Temeyer, Jeff McClenathan, Tom Scott, Joe Rohde, Gary Rubingh, Wally Stern, Doug Clemetson, and Tom Westenburg, MRO, and Jerry Holloway, MRK, visited WES during the study to discuss test results and to correlate these results with concurrent design work.

COL Larry B. Fulton, EN, is the present Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)

UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet per second | 0.02831685 | cubic metres per second |
| feet | 0.3048 | metres |
| feet per second | 0.3048 | metres per second |
| pounds | 0.4535924 | kilograms |

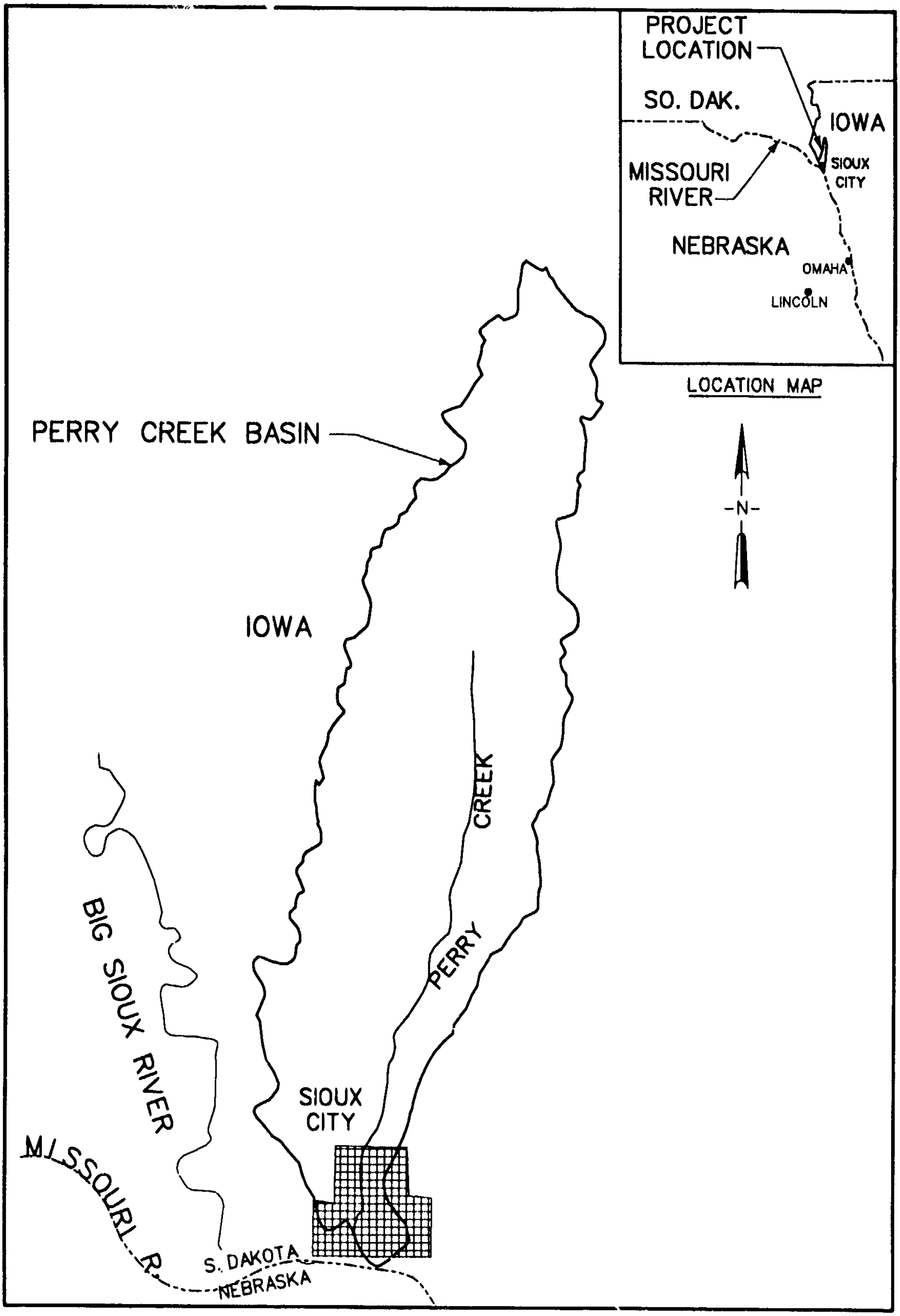


Figure 1. Vicinity map

PERRY CREEK CONDUIT

SIOUX CITY, IOWA

Hydraulic Model Investigation

# PART I. INTRODUCTION

## The Prototype

1. Perry Creek Conduit is located on Perry Creek in Sioux City, Iowa (Figure 1). The existing conduit begins at Perry Creek sta 43+00 and ends at sta 2+32, approximately 250 ft* from the left bank of the Missouri River. The existing conduit ranges in width from 39 to 50 ft and also has an open channel section between sta 11+30 and 10+70.

2. Perry Creek has less than 10-year flood frequency protection with its present channel and conduit. A proposed plan of improvement by the US Army Engineer District, Omaha, will provide 100-year flood frequency protection along a portion of Perry Creek by making channel and conduit modifications. The initial improvements included replacing the existing conduit with a 52-ft-wide conduit from sta 44+10 to 10+22 and extending the conduit entrance to sta 44+50. Plans indicated the invert would be lowered between sta 10+22 and 2+32 and a stilling basin would be constructed, if necessary, at the outlet.

## Purpose and Scope of Model Investigation

3. The purpose of the model investigation reported herein was to evaluate the performance of the proposed design and develop desirable modifications, if needed, to safely pass the 100-year frequency discharge of 16,000 cfs through the conduit. Specific areas of interest were:

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

a. The conduit entrance transition from the proposed trapezoidal approach channel to rectangular concrete tunnel.

b. The conduit curves and their effect on supercritical flow conditions.

c. The transition from the proposed conduit into the existing conduit with a lowered invert.

d. The existing conduit outlet to determine the need for energy dissipation.

## PART II: THE MODEL

### Description

4. A 1:25-scale model (Figure 2 and Plate 1) was designed and constructed and reproduced 700 ft of approach channel to the conduit, the entire conduit (sta 44+50 to 2+32), and approximately 250 ft downstream from the outlet. The approach and, initially, the exit channel were molded in sand and cement mortar to sheet metal templates. Later the cement mortar in the exit channel was replaced with riprap and sand to determine the size and extent of outlet channel protection required. The straight sections of the conduit were constructed of transparent plastic. The curve sections of the conduit were built with the invert finished in very smooth concrete and the sides of plastic.

### Model Appurtenances

5. Water used in the operation of the model was supplied by a

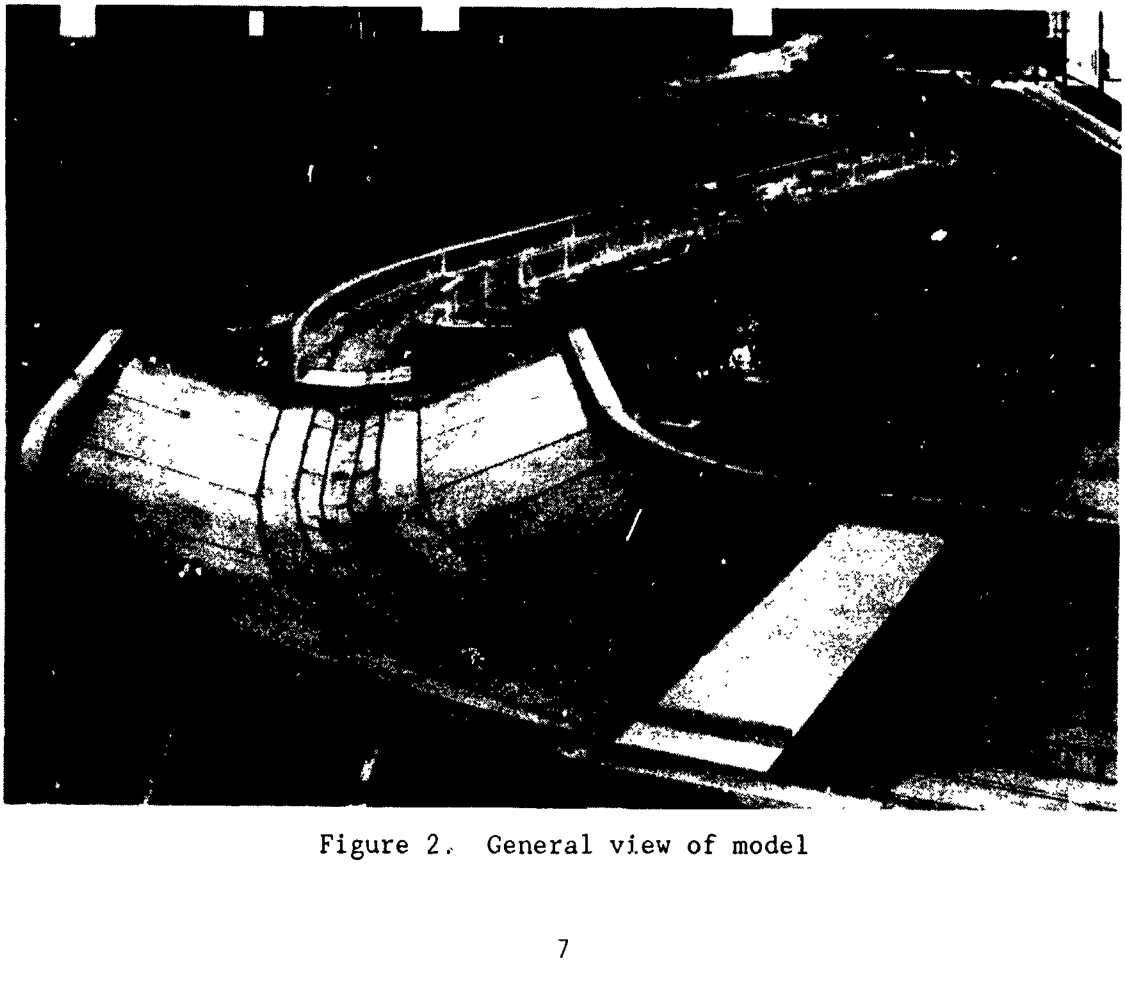

Figure 2. General view of model

circulating system. Discharges were measured with propeller-type flow meters installed in the inflow lines and were baffled before entering the model. Velocities were measured with pitot tubes that were mounted to permit measurement of flow from any direction and at any depth. Water-surface elevations were measured with point gages, and different designs and various flow conditions were recorded photographically.

## Scale Relations

6. Similitude was achieved in the model based on the Froude criteria. Geometric and kinematic similitude were maintained and the model Reynolds number was high enough to ensure rough turbulent flow. The mathematical relations between the dimensions and hydraulic quantities of the model and prototype based on Froude criteria are shown in the following tabulation along with the general relations for the transference of model data to prototype equivalents for a 1:25-scale model. Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype by the scale relations. Experimental data also indicate that the model-to-prototype scale ratio is valid for scaling riprap in the sizes used in this investigation.

| Characteristic | Dimension* | Scale Relations Model:Prototype |
|---|---|---|
| Length | $L_r$ | 1:25 |
| Area | $A_r = L_r^2$ | 1:625 |
| Velocity | $V_r = L_r^{1/2}$ | 1:5 |
| Time | $T_r = L_r^{1/2}$ | 1:5 |
| Discharge | $Q_r = L_r^{5/2}$ | 1:3,125 |
| Weight | $W_r = L_r^3$ | 1:15,625 |
| Roughness coefficient | $N_r = L_r^{1/6}$ | 1:1.71 |

* Dimensions are in terms of length.

## Model Adjustments

7. Manning's n , a coefficient of roughness, for the model conduit was

approximately 0.009. This is equivalent to a prototype n of 0.015. The initial testing program included plans for tests with equivalent prototype n values of 0.013 and 0.015. The lower n value was to be tested to design the energy dissipator and the higher n value was to be tested to determine the capacity of the conduit. Since determining the capacity of the conduit was the main purpose of the model investigation, the tests with the equivalent prototype n of 0.015 were conducted first. This meant no model adjustments were needed since a model n value of 0.009 is equivalent to a prototype n value of 0.015 at a 1:25 scale. During the course of the investigation, the tests with an equivalent prototype n of 0.013 were canceled.

## PART III: TESTS AND RESULTS

### Initial Tests of Conduit

8. The initial tests were conducted to observe flow conditions in the conduit with the original design and determine the capacity of the conduit. The prototype conduit is situated below the city streets in Sioux City with the conduit sized for open channel flow conditions during flood flows. Adequate freeboard was designed so the water surface would not come in contact with the roof and cause pressurized flow conditions in the conduit. The roof was not installed in the model so that water-surface elevations could be measured and compared to roof elevations.

9. Flow conditions were observed with increasing discharges through the conduit and no tailwater effect at the outlet. With a discharge of 10,200 cfs, flow began to spill over the right wall at sta 32+50, curve 5 shown in Plate 1, and the left wall at sta 22+50, curve 4 shown in Plate 1 and Photo 1. The walls were 20 ft higher than the invert of the channel. The bend losses were higher than anticipated causing the flow regime to change from supercritical flow approaching the bend to subcritical flow through the bend. This resulted in the formation of a weak hydraulic jump with standing waves which overtopped the walls. The hydraulic jump in the vicinity of sta 22+50 is shown in Photo 2 with a discharge of 5,000 cfs through the curve.

10. Tests were conducted to ensure that the higher than expected bend losses were not the result of the different materials used in the construction of the curve sections. Manning's n values were determined for three different discharges with a section of channel constructed with just plastic and a section where the walls were constructed of plastic with a smooth concrete finish on the invert. Test results indicated there were no significant differences in the Manning's n values between the section built entirely of plastic and the section built of plastic and smooth concrete.

11. The proposed channel and conduit were designed to contain the 100-year frequency flow of 16,000 cfs. The excessive bend losses reduced the capacity to 10,200 cfs, which was not acceptable. Flow conditions in the approach channel, approach transition, conduit, conduit transition, and outlet area were documented and are discussed in the following paragraphs.

Approach to the conduit

12. Flow conditions in the approach channel to the conduit for discharges of 5,000 and 10,200 cfs are shown in Photos 3 and 4, respectively. Pier contractions around the Bluff Street Bridge piers were evident, but did not appear to be severe. The water surface downstream from the bridge was more choppy than the water surface upstream as a result of the bridge and bend losses.

Approach transition

13. Flow conditions in the approach transition for discharges of 5,000 and 10,200 cfs are shown in Photos 5 and 6, respectively. The performance of the transition for these discharges was satisfactory and the transition losses were not excessive.

Conduit

14. Flow conditions in the conduit for a discharge of 10,200 cfs are shown in Photo 7. Flow conditions in curves 1 and 2, as discussed in paragraph 9, are shown in Photo 7a and a closeup view of the flow at the beginning of the second conduit curve is shown in Photo 7b. This photo illustrates the weak undular jump that forms as flow transitions from super- to subcritical due to the bend losses in the curve. Flow conditions from sta 24+12.62 to the end of the conduit (sta 2+32) are shown in Photo 7c, and again the buildup of the water surface due to the bend losses can be seen in the third conduit curve. A water-surface profile throughout the conduit is shown in Plate 2 for a discharge of 10,200 cfs. Velocities measured at several locations for discharges of 3,500, 7,000, and 10,200 cfs are shown in Plates 3-5, respectively.

Conduit transition

15. Flow conditions in the transition section where the conduit width is reduced from 52 to 50 ft (sta 10+90 to 10+60) are shown in Photo 8 for discharges of 5,000 and 10,200 cfs. Flow was near critical from sta 10+60 to 2+32, as shown in Photo 9, for discharges of 5,000 and 10,200 cfs, resulting in standing waves in this area. Details of the conduit transition are shown in Plate 6.

Scour hole and exit channel

16. Details of the original design exit channel are shown in Plate 7. The exit area was initially molded in sand and cement mortar so flow conditions in the conduit could be readily changed without destroying the exit channel. Since the originally designed conduit would not pass the design

discharge, the exit channel was not thoroughly tested; however, flow conditions were documented with photographs. Flow conditions at the end of the conduit for a discharge of 10,200 cfs and a minimum tailwater elevation of 1076* (Missouri River discharge of 35,000 cfs) are shown in Photo 10. The jet flow plunged into the tailwater causing a strong flow concentration in the center of the exit channel and intensified side flow circulations as illustrated in Photo 10b. Large surface waves occurred in the exit channel as a result of the concentrated flow and strong side eddies. These same type of flow conditions were observed with a discharge of 10,200 cfs and the maximum tailwater elevation of 1084 (Missouri River discharge of 75,000 cfs), Photo 10c. However, the surface waves were not as large. Flow conditions in the exit channel with a discharge of 5,000 cfs are shown in Photo 11. The flow plunged into the exit channel with a tailwater elevation of 1076 (Photo 11b), but as the tailwater elevation was increased to 1084 (Photo 11c), the flow began to ride the surface of the tailwater causing large surface waves.

## Reconstructed Model

17. The Omaha District provided another design after excessive bend losses were encountered with the original design. Basic changes included extending the subcritical approach channel to sta 25+20, starting the 50-ft-wide conduit at sta 24+40, and lowering the invert of the conduit. The reconstructed model, designated the type 2 design channel, is shown in Figure 3, and a general plan is shown in Plate 8. Plan, profile, and section views of the approach channel, approach channel transition, and conduit are shown in Plate 9. Plan, profile, and section views of the conduit transition are shown in Plate 10.

18. Initial tests were conducted to observe the performance of the type 2 design channel with increasing discharges. The tests indicated the conduit would pass a discharge of 16,000 cfs between sta 25+20 and 10+90, but the capacity was reduced to just over 14,000 cfs downstream of sta 10+90, the start of the channel transition. Large standing waves were observed in the vicinity of the transition and the flow appeared to be near critical.

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* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Figure 3. Type 2 design channel

Approach channel

19. The wall height was increased to contain the flow through the conduit transition in order to document flow conditions upstream of the transition. Flow conditions in the approach channel with discharges of 2,000, 8,000, and 16,000 cfs are shown in Photos 12-14, respectively. Flow conditions were satisfactory and contractions around the bridge piers for the berm flows did not adversely affect the approach flow.

Approach transition

20. Flow conditions in the approach transition for discharges of 2,000,

8,000, and 16,000 cfs are shown in Photos 15-17, respectively. The transition losses were not excessive and the transition loss coefficient $C_c$, as given in EM 1110-2-1601,* determined from water-surface elevations and computed average velocities for sta 26+00 and 23+20 was 0.18 with a discharge of 16,000 cfs.

<u>Conduit and conduit transition</u>

21. Flow conditions in the upper portion (sta 24+40 to 10+90) of the conduit for discharges of 2,000, 8,000, and 16,000 cfs can be seen in Photos 15-17, respectively. The flow conditions between sta 10+90 and 2+32 are shown in Photos 18-20 for discharges of 2,000, 8,000, and 16,000 cfs, respectively. As mentioned previously, a problem area was observed at the transition where the capacity of the conduit was just over 14,000 cfs. The transition losses caused the flow regime to change from supercritical to critical resulting in an excessive increase in the water depth. Photo 21 shows a side view of the flow conditions through the transition. The model wall height was increased to contain the flow, with the actual wall height outlined in the photograph. Water-surface profiles for discharges of 16,000 and 10,200 cfs are shown in Plates 11 and 12, respectively.

22. The length of the transition was increased from 30 ft (original design) to 200 ft (type 2 transition) with the transition beginning at sta 12+60. The details of the type 2 transition are shown in Plate 13. The invert of the channel transitioned in 100 ft (sta 11+60 to 10+60), and the channel berms transitioned between sta 12+60 and 10+60. Photo 22 shows the improved flow conditions with the type 2 transition. With the type 2 transition, flow conditions in the entire conduit, sta 24+20 to 2+32, were satisfactory for discharges up to 16,000 cfs. Water-surface profiles through the type 2 transition for a discharge of 16,000 cfs are shown in Plate 14. The maximum discharge before flow began hitting the roof was determined to be 20,200 cfs with the type 2 transition. The station where the flow initially hit the roof was 5+35. Velocities were also measured at the downstream end of the conduit (sta 2+32) for various flow conditions and are shown in Plate 15.

<u>Exit channel</u>

23. One of the purposes of the model study was to determine if a cutoff

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* Headquarters, US Army Corps of Engineers. 1970 (1 Jul). "Hydraulic Design of Flood Control Channels," EM 1110-2-1601, US Government Printing Office, Washington, DC.

wall and preformed scour hole, lined with riprap, would provide adequate protection at the conduit outlet. The exit channel was remolded of sand and riprap to test the effectiveness of the riprap scour hole. The details of the scour hole are shown in Plate 16 and the riprap gradation is shown in Plate 17. A dry-bed photo of the riprap scour hole is shown in Photo 23.

24. Tests were conducted to determine the stability of the riprap for various discharges with the maximum and minimum tailwater elevations of 1084 and 1074 (Missouri River discharge of 28,000 cfs), respectively. The riprap in the scour hole was stable with a tailwater elevation of 1084 for discharges up to 10,000 cfs. Higher discharges resulted in failure of the horizontal portion of the invert riprap approximately 80 to 90 ft downstream from the end of the conduit. The riprap in the scour hole was unstable for discharges greater than 4,000 cfs with a tailwater elevation of 1074. The riprap on the 1V on 2H downslope and approximately 50 ft of the horizontal portion of the invert riprap failed with discharges higher than 4,000 cfs. Results of these tests indicated that riprap would not be adequate to prevent excessive scour in the exit area with the design discharge. A stilling basin will be necessary to protect this area. Personnel in the Omaha District will design this basin and they decided that model tests of this design would not be needed. Thus, no additional tests were conducted.

Recommended design

25. Based on test results, the type 2 design channel with the type 2 design transition contained the design discharge of 16,000 cfs. Therefore, these modifications are recommended. Water-surface profiles and Froude numbers at several locations for the design discharge of 16,000 cfs are provided in Plate 18.

## PART IV: SUMMARY AND RECOMMENDATIONS

26. Model tests revealed the capacity of the original design flood control channel was 10,200 cfs. The design discharge was 16,000 cfs. Discharges greater than 10,200 cfs caused the flow to hit the roof of the existing conduit in the second and third conduit curves from the upstream end of the conduit (curves 4 and 5, Plate 1). This was not acceptable. Excessive bend losses occurred in the original design curves causing the flow regime to transition from supercritical flow entering the curves to subcritical flow through the curves and then back to supercritical flow exiting the curves. The performance of the original design stilling basin and exit channel was documented with photographs. Flow conditions in the original design conduit were not acceptable.

27. Performance of the reconstructed model, described in paragraph 17, was satisfactory between sta 25+20 and 10+90 with a discharge of 16,000 cfs. However, the capacity of the conduit downstream from sta 10+90 in the reconstructed transition was only 14,000 cfs. The transition was modified by allowing the channel berms to transition between sta 12+60 and 10+60 and the channel invert to transition between 11+60 and 10+60. With this modification, flow conditions were satisfactory throughout the entire conduit.

28. The riprap scour hole with the reconstructed model was found to be stable for discharges up to 4,000 cfs with minimum tailwater conditions (el 1074, Missouri River discharge of 28,000 cfs) and was stable for discharges up to 10,000 cfs for maximum tailwater conditions (el 1084, Missouri River discharge of 75,000 cfs). Additional tests to improve the performance of the scour hole were not conducted since a stilling basin was considered necessary to dissipate the energy of the flow exiting the conduit. Project management decided tests to verify the stilling basin designed by the Omaha District were not necessary.

29. The model indicated that the type 2 design channel and type 2 design transition will contain the design discharge of 16,000 cfs. These modifications are therefore recommended. A stilling basin is recommended at the end of the conduit to dissipate the energy of the exiting flow. The scenario that would produce the most severe conditions in the exit channel would be a design flow in the Perry Creek Conduit with a minimum Missouri River stage. A stilling basin that performs adequately for these conditions is recommended. A

design event in the Perry Creek Conduit with a maximum stage on the Missouri River would probably result in marginal energy dissipation in a conventional-type stilling basin. Therefore, additional bank protection is recommended in the vicinity of the Perry Creek stilling basin and on the opposite bank of the Missouri River.

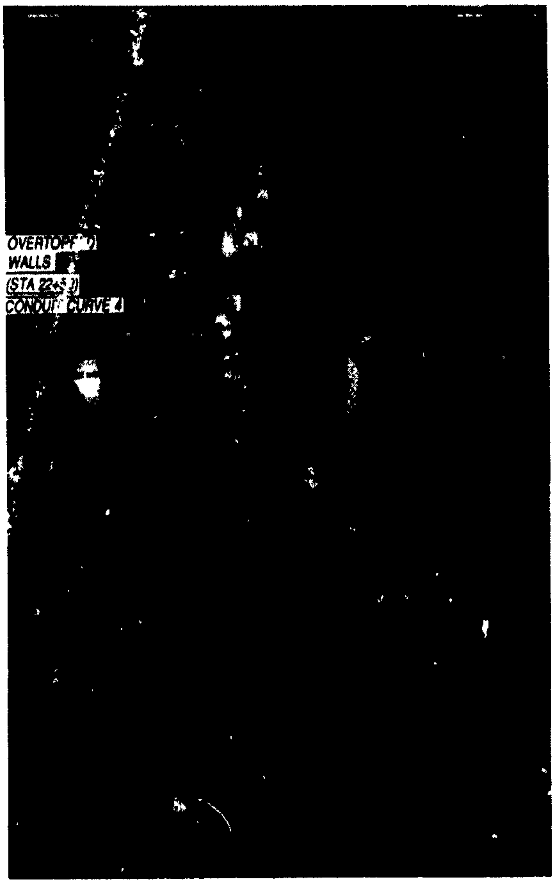



Photo 1. Flow conditions in original design conduit downstream from sta 24+12.62.
Q = 10,200 cfs


Photo 2. Flow conditions in original design conduit downstream from sta 24+12.62.
Q = 5,000 cfs

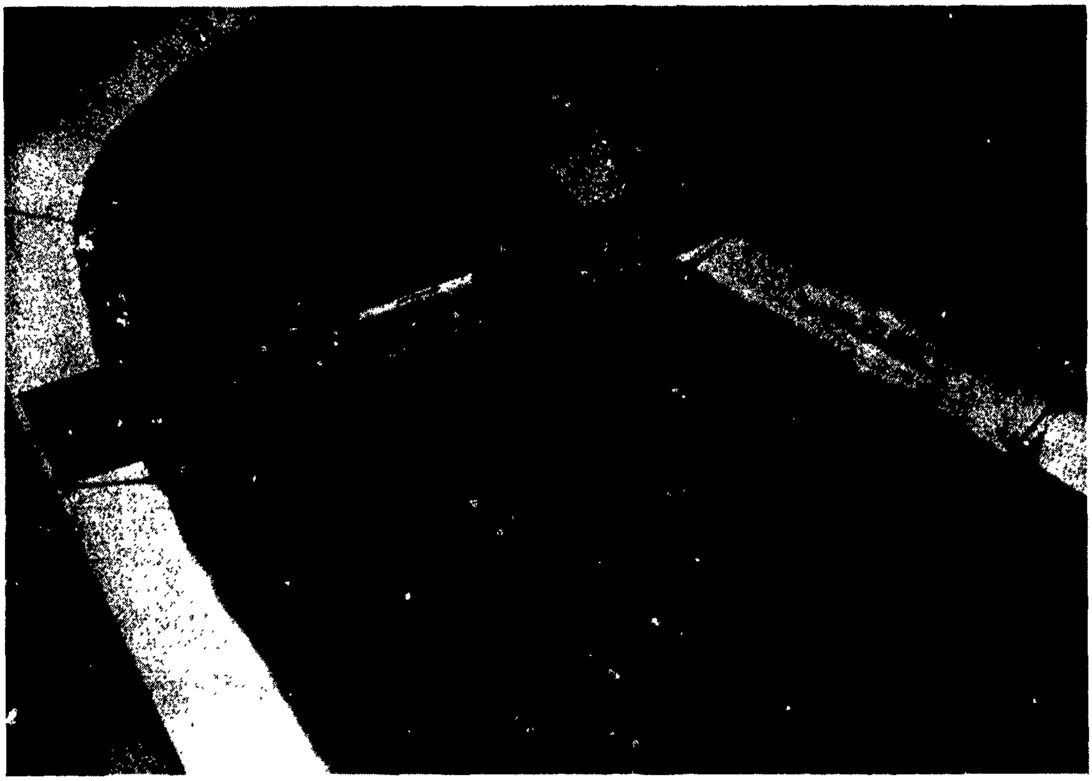


Photo 3. Flow conditions in original design approach channel at Bluff Street Bridge. Q = 5,000 cfs

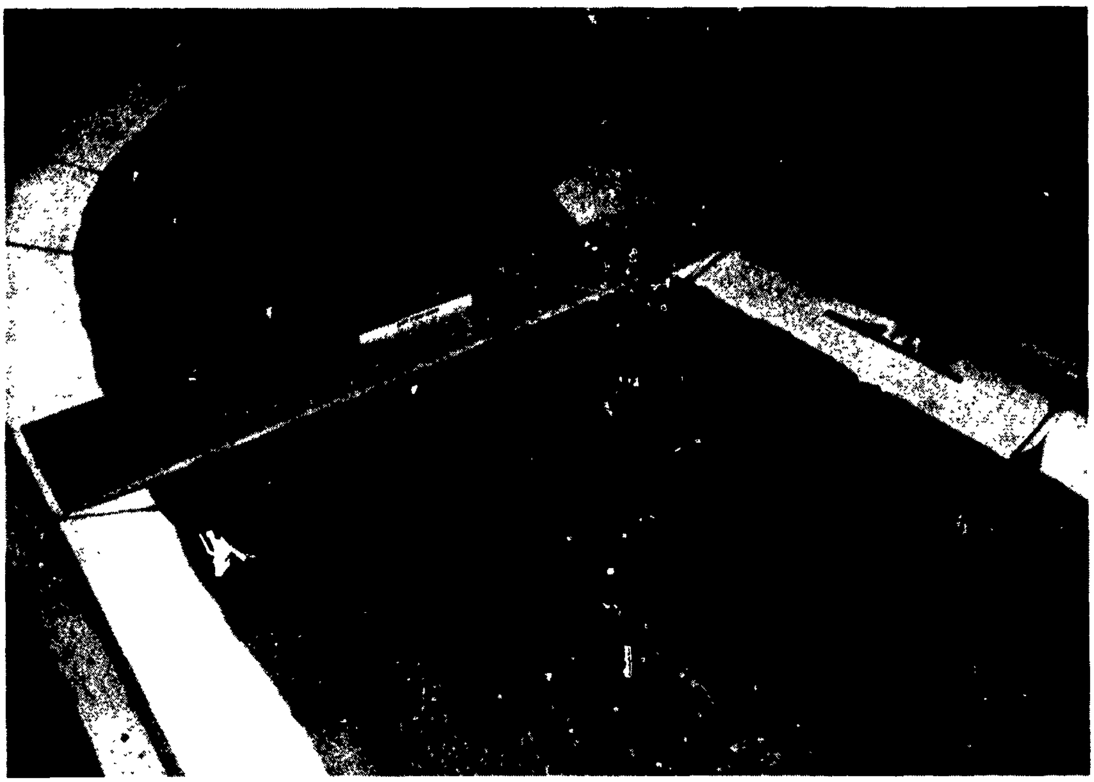


Photo 4. Flow conditions in original design approach channel at Bluff Street Bridge. Q = 10,200 cfs

Photo 5. Flow conditions in original design approach channel transition. Q = 5,000 cfs

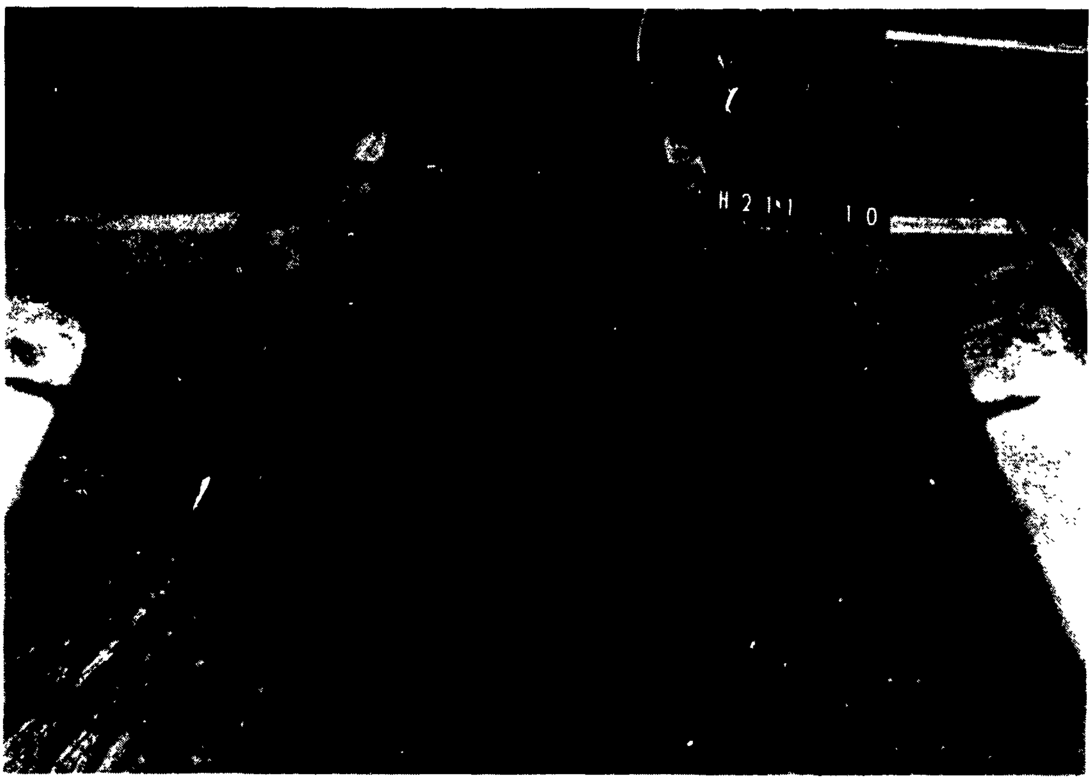
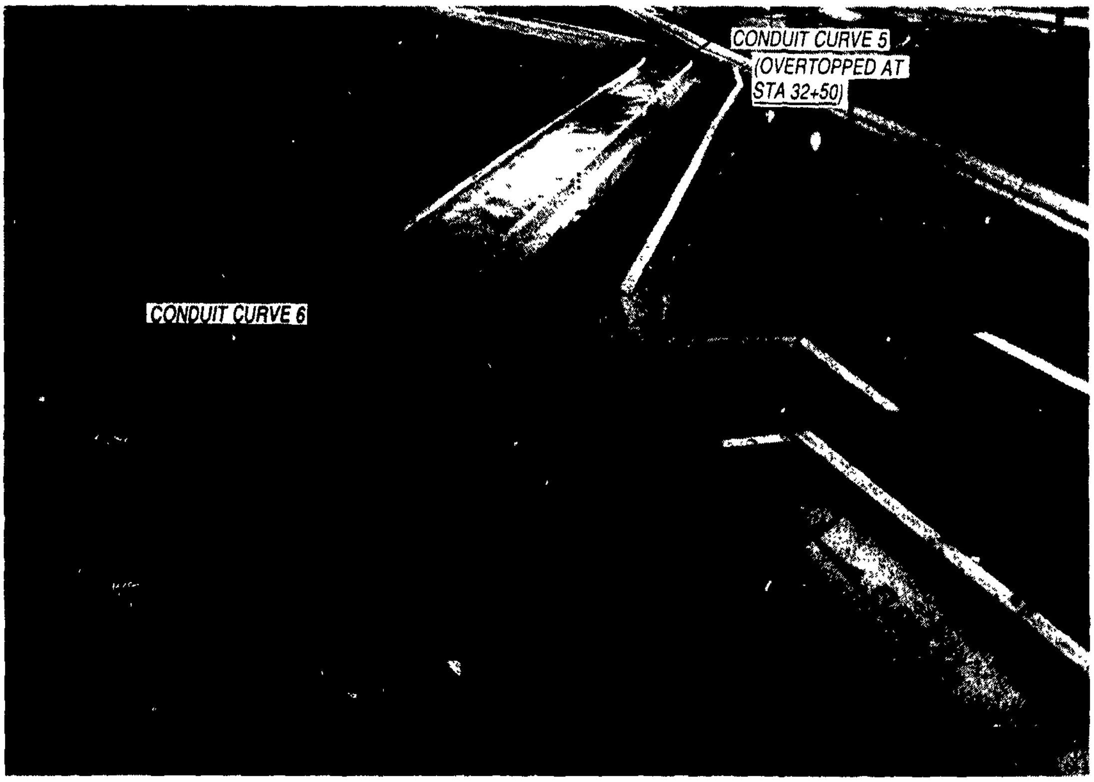
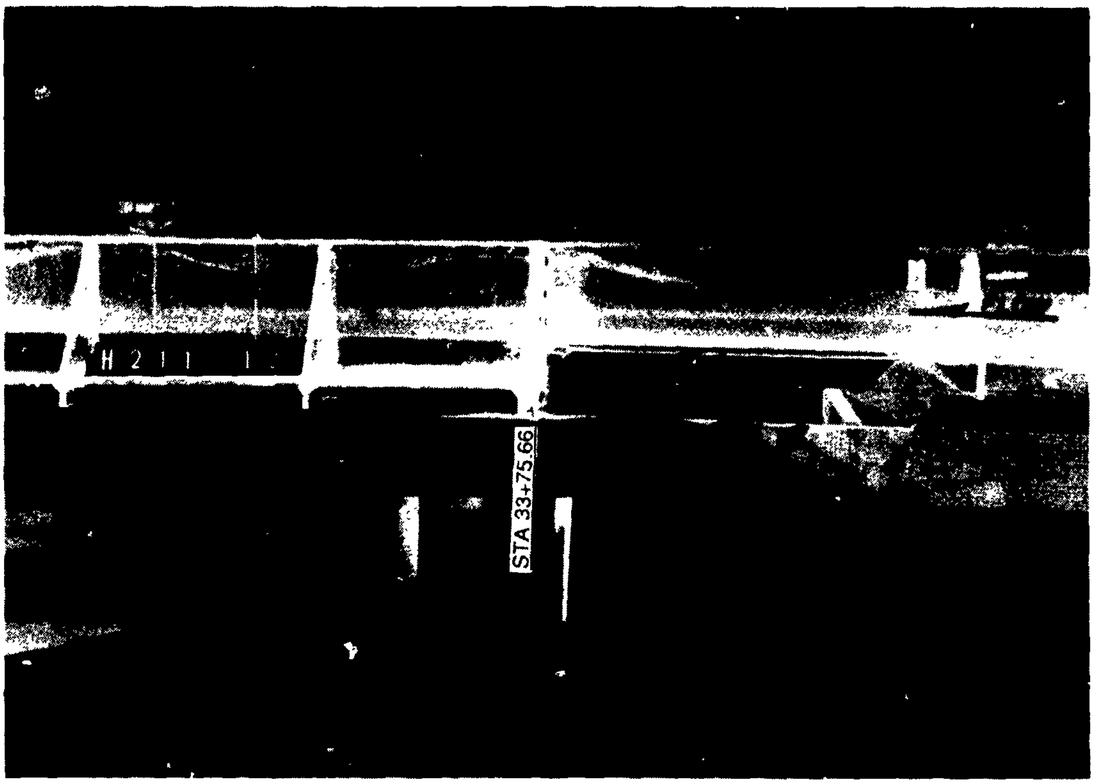


Photo 6. Flow conditions in original design approach channel transition. Q = 10,200 cfs

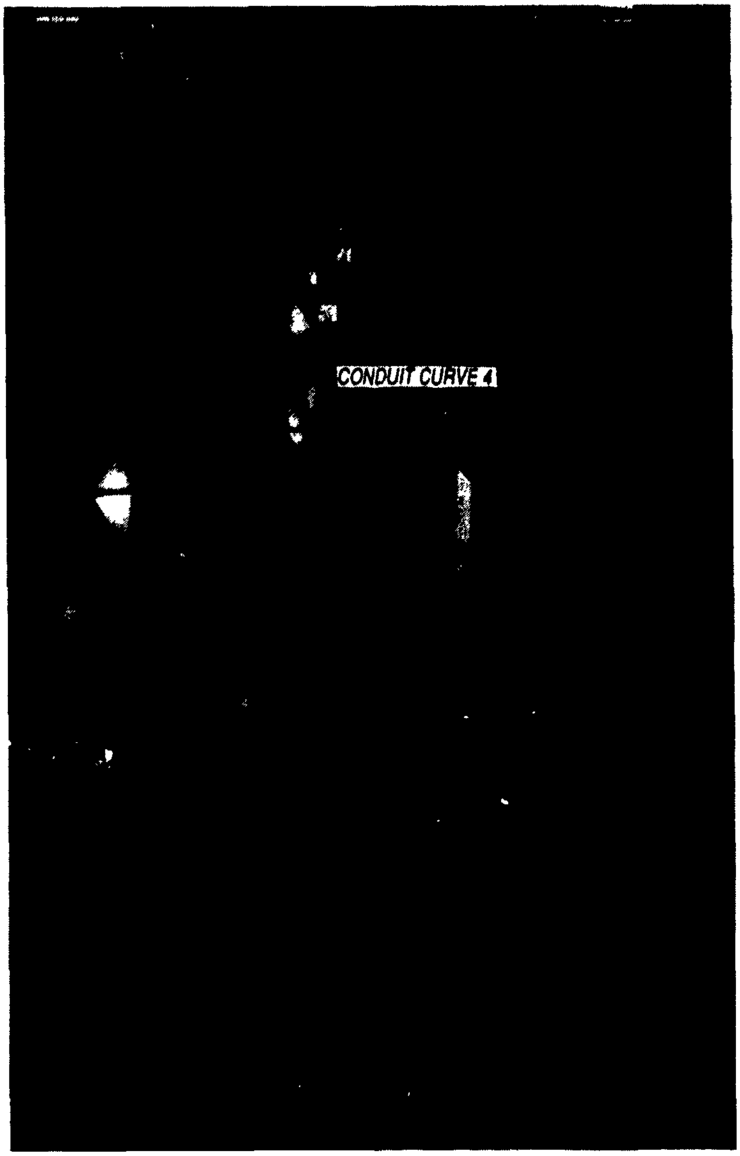



a. Approach and channel downstream to sta 34+00




b. Flow transitions from supercritical to subcritical in curve 5

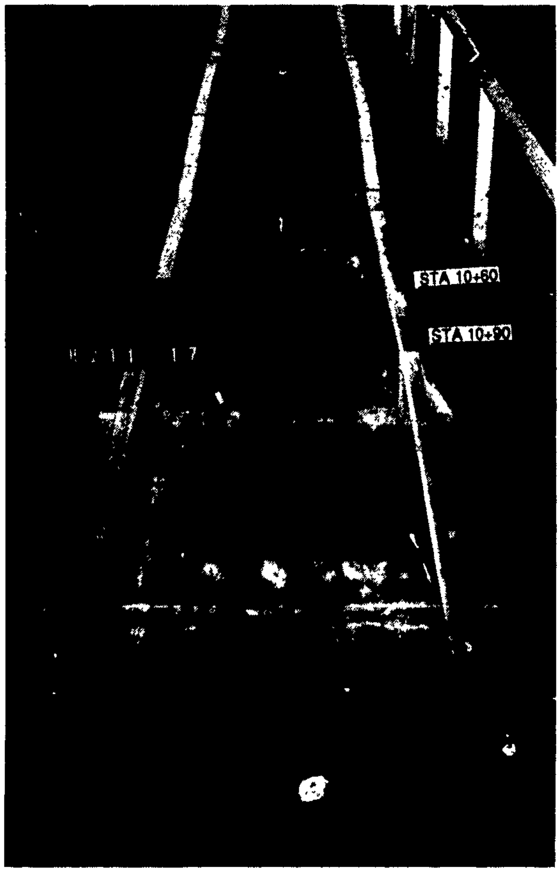
Photo 7. Flow conditions in original design conduit, curves 6, 5, and 4 (Continued)




c. Sta 24+12.62 to sta 2+32

Photo 7. (Concluded)

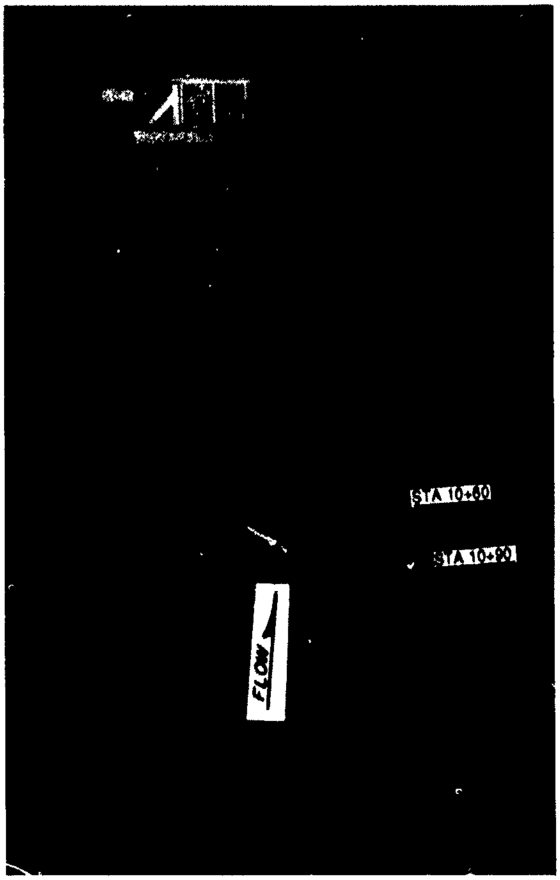
a. Q = 5,000 cfs



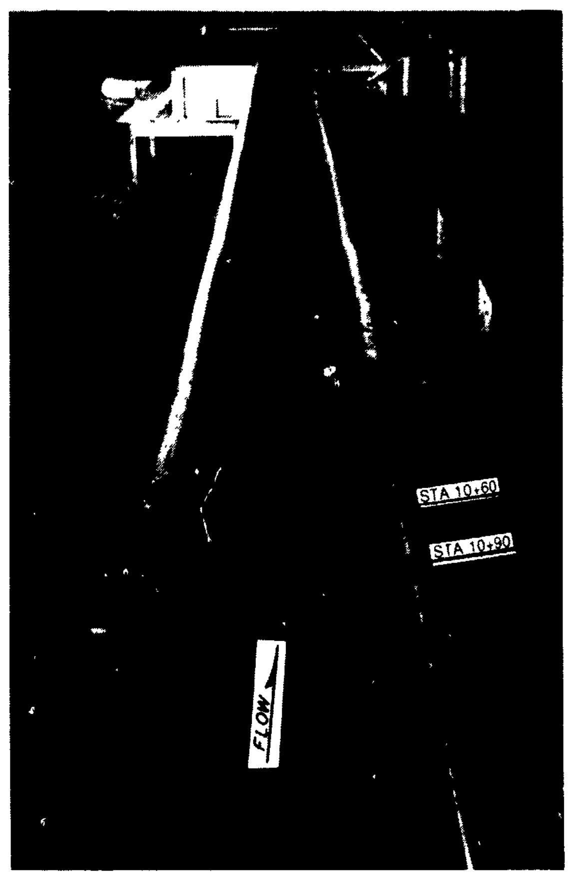


b. Q = 10,200 cfs

Photo 8. Flow conditions in original design transition section between sta 10+90 and 10+60



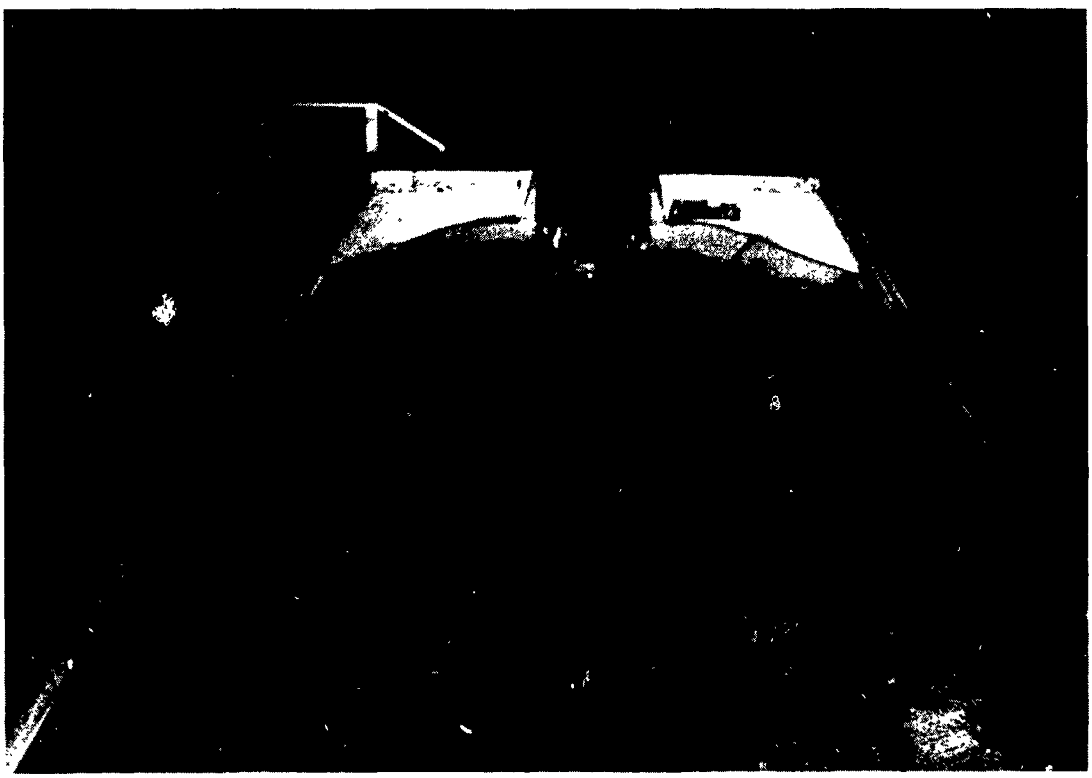

a. Q = 5,000 cfs




b. Q = 10,200 cfs

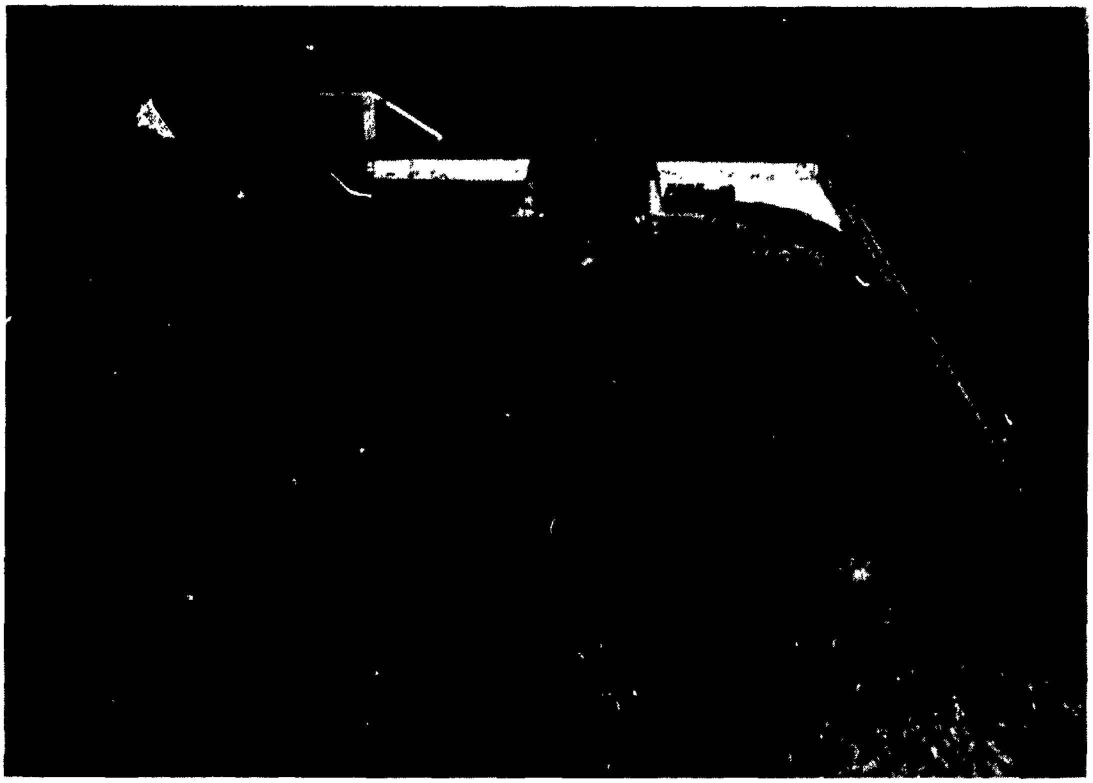
Photo 9. Near critical flow conditions in original design transition section between sta 10+60 and 2+32

a. At sta 2+32; TW el = 1076



b. At scour hole; TW el = 1076

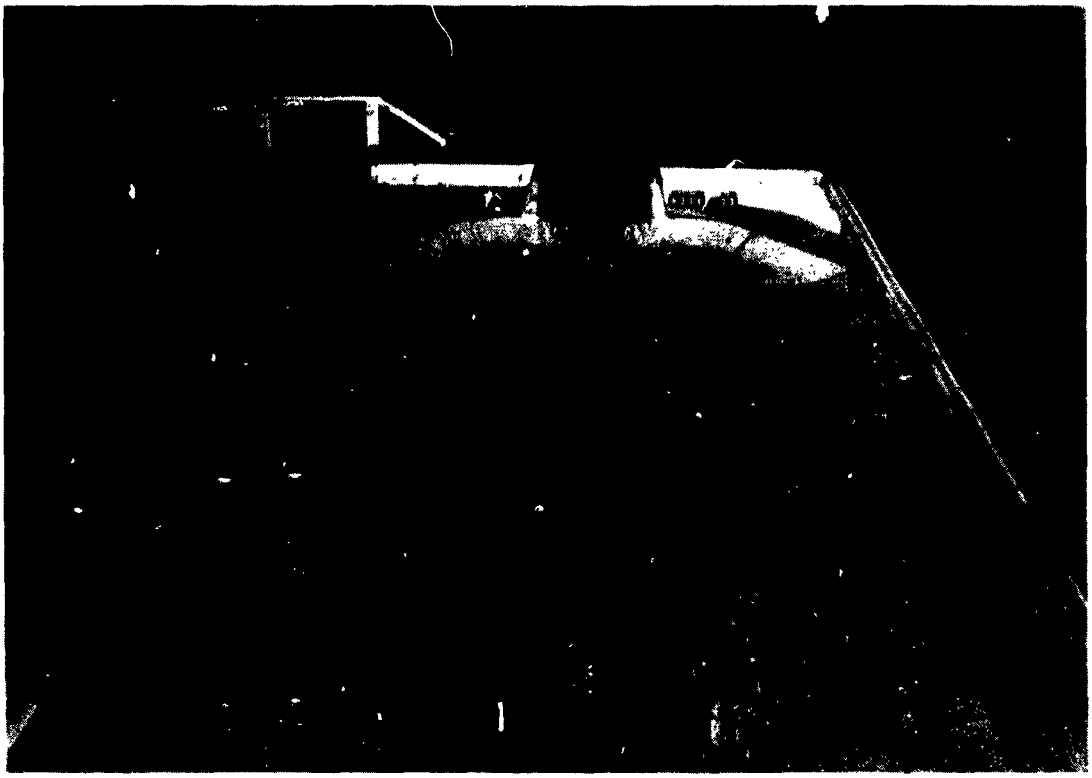
Photo 10. Flow conditions in original design exit channel at 10,200 cfs (Continued)



c. At scour hole; TW el = 1084

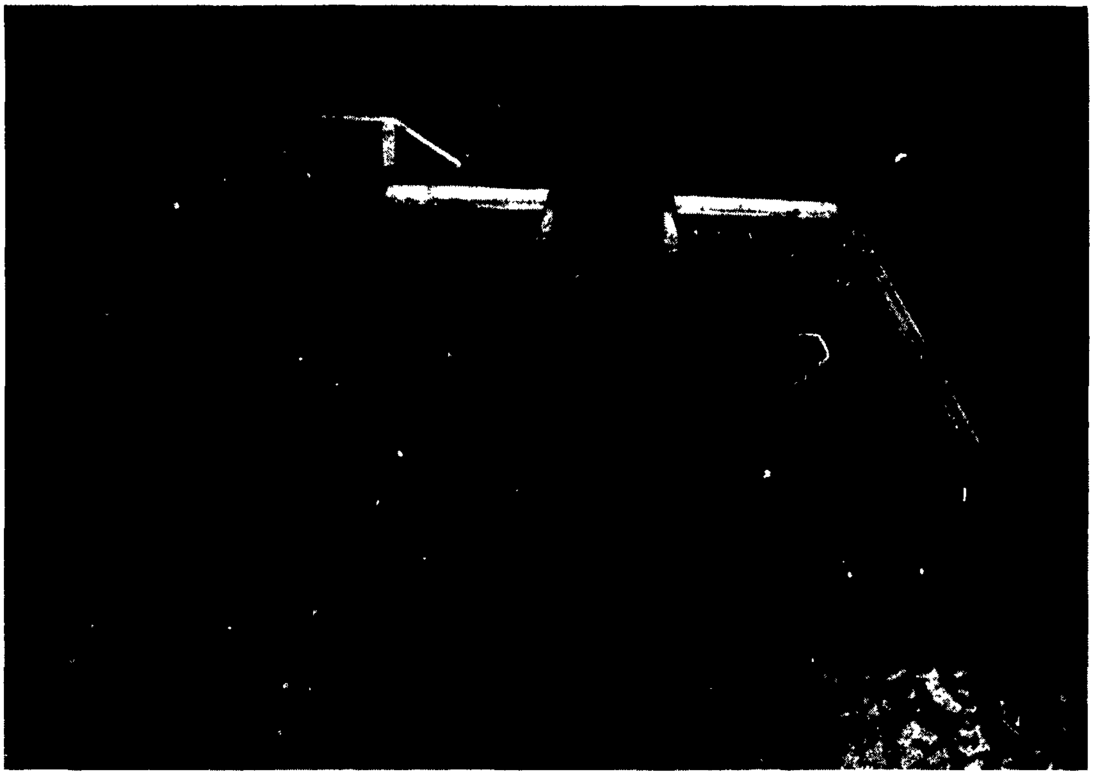
Photo 10. (Concluded)

a. At sta 2+32; TW el = 1076



b. At scour hole; TW el = 1076

Photo 11. Flow conditions in original design exit channel at 5,000 cfs (Continued)



c. At scour hole; TW el = 1084

Photo 11. (Concluded)

Photo 12. Flow conditions in type 2 design approach channel. Q = 2,000 cfs

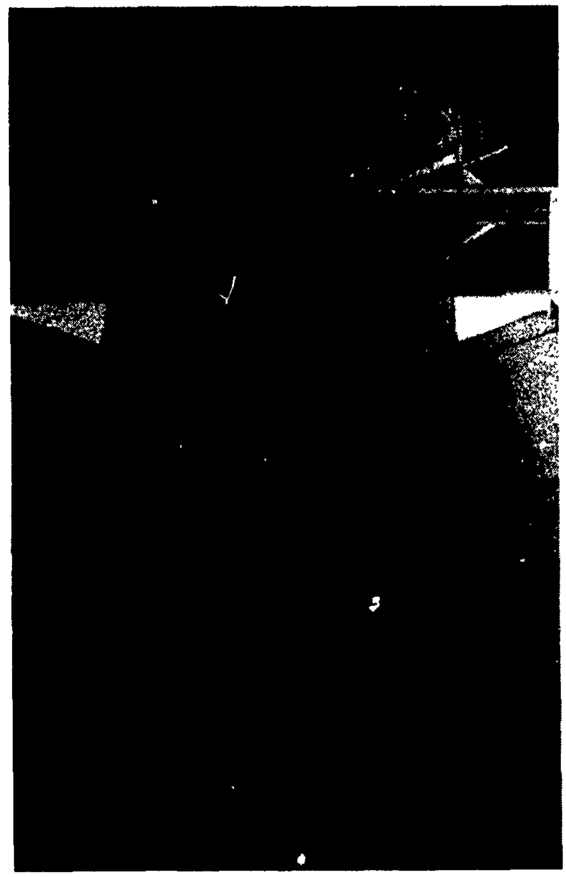


Photo 13. Flow conditions in type 2 design approach channel. Q = 8,000 cfs

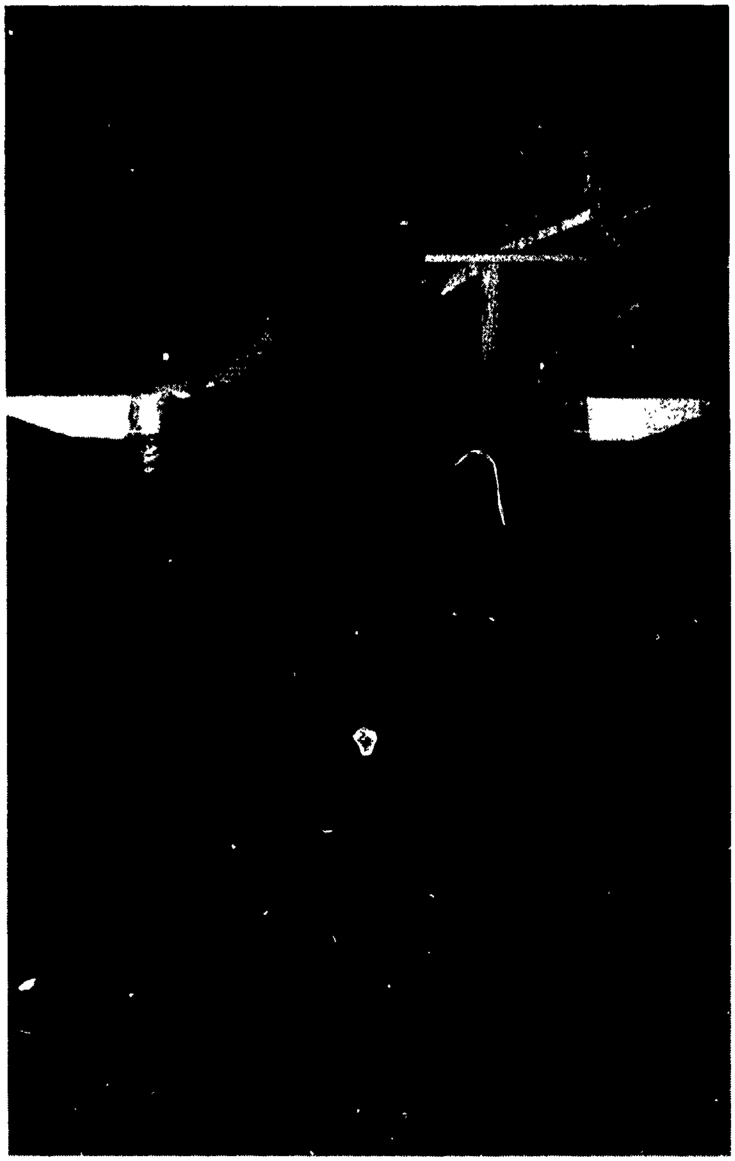


Photo 14. Flow conditions in type 2 design approach channel. Q = 16,000 cfs

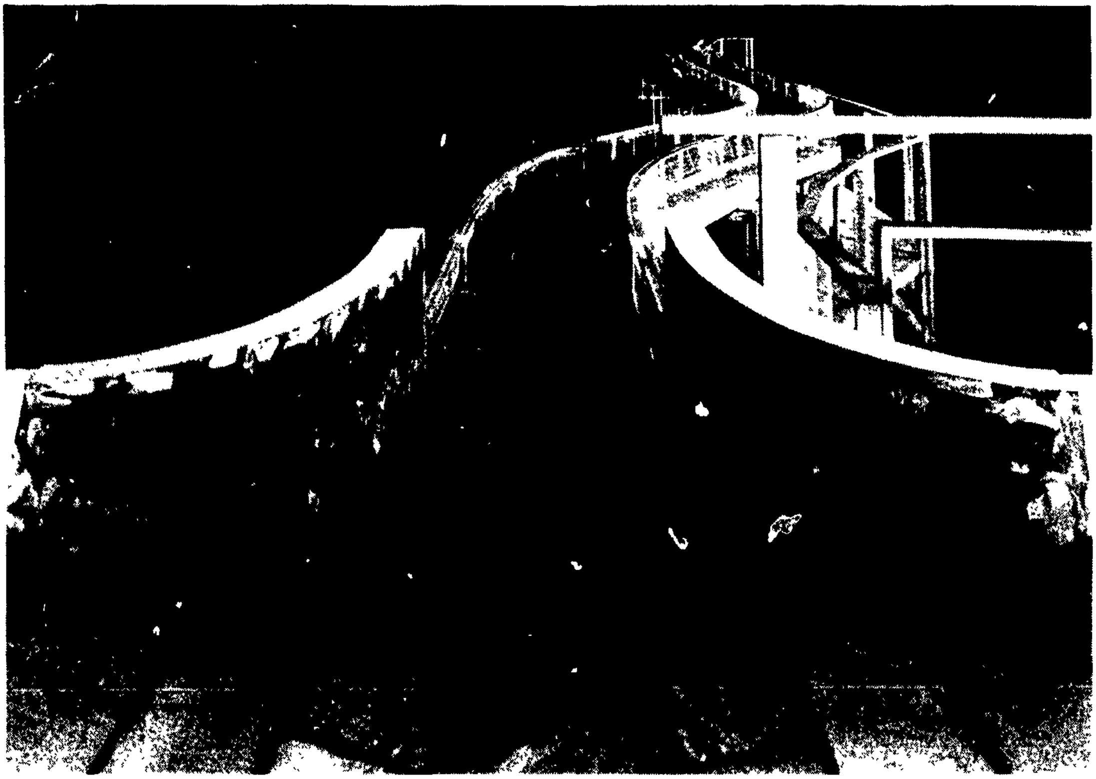
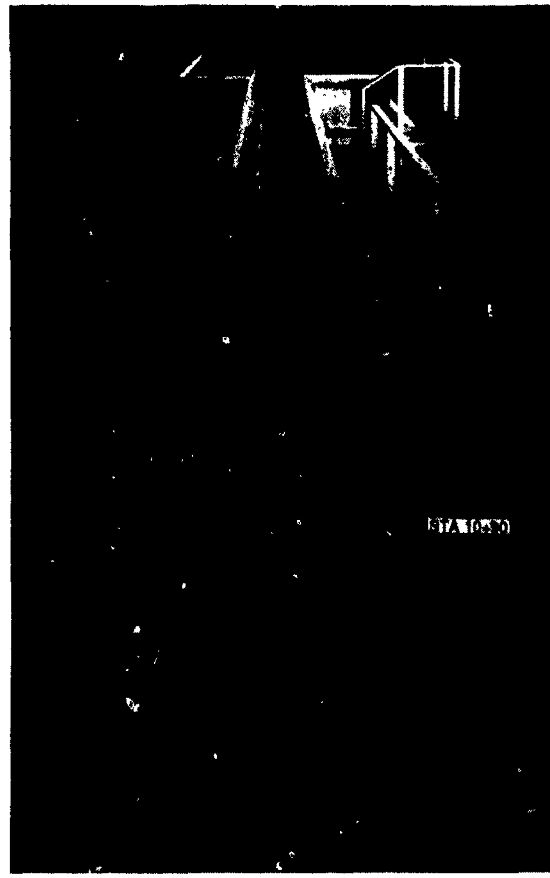


Photo 15. Flow conditions in type 2 design approach channel transition. Q = 2,000 cfs

Photo 16. Flow conditions in type 2 design approach channel transition. Q = 8,000 cfs

Photo 17. Flow conditions in type 2 design approach channel transition. Q = 16,000 cfs

Photo 18. Flow conditions in type 2 design, type 1 transition, downstream from sta 10+90. Q = 2,000 cfs



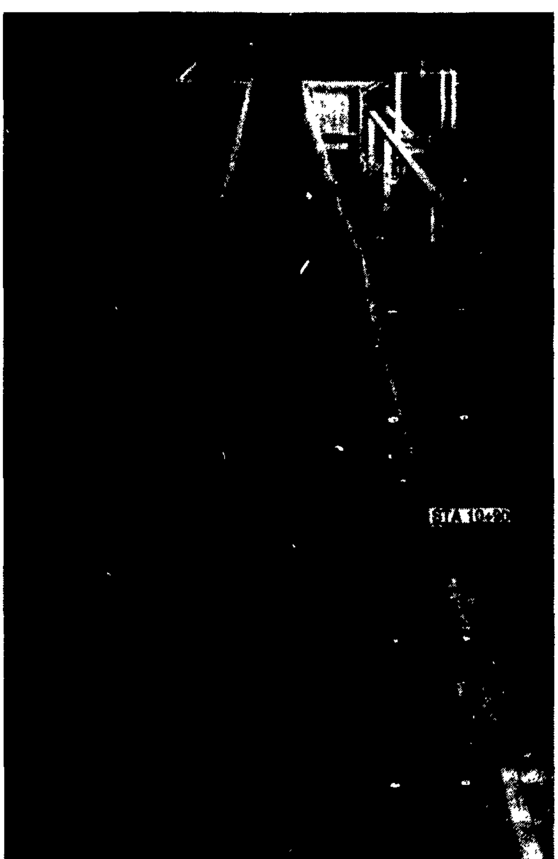


Photo 19. Flow conditions in type 2 design, type 1 transition, downstream from sta 10+90. Q = 8,000 cfs

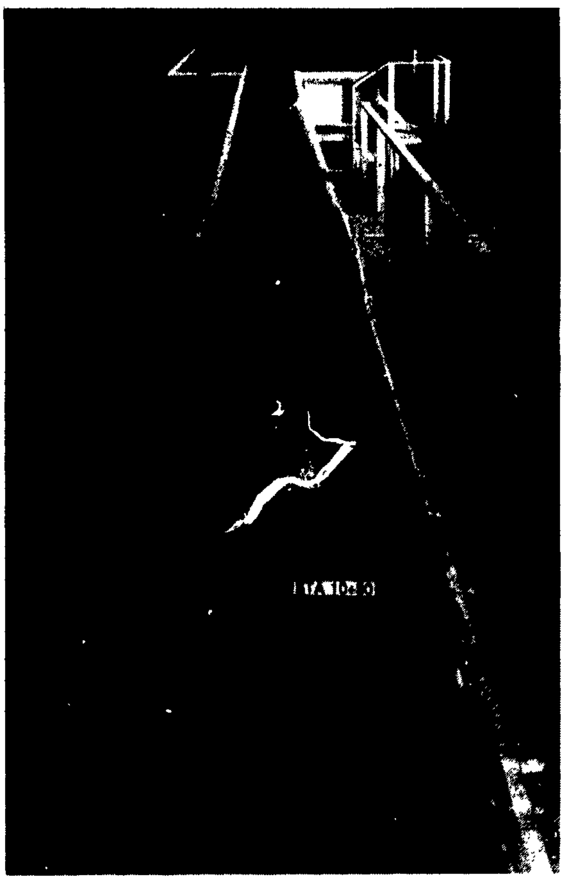


Photo 20. Flow conditions in type 2 design, type 1 transition, downstream from sta 10+90. Q = 16,000 cfs

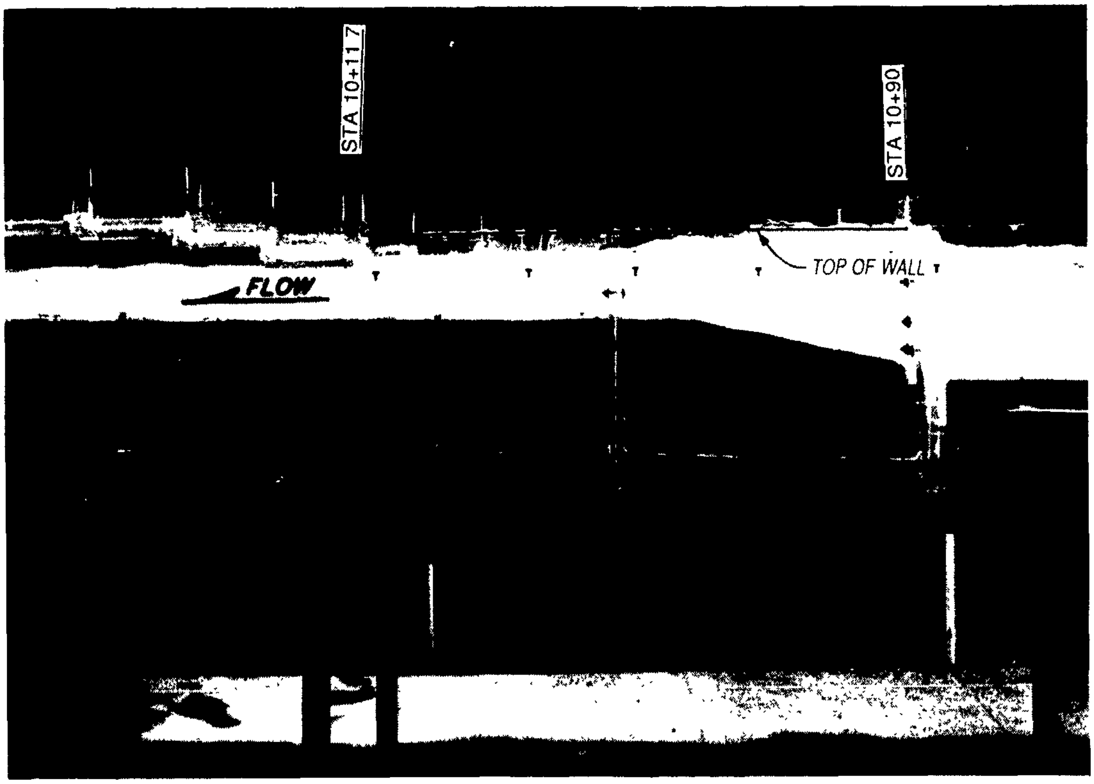



Photo 21. Side view of flow conditions in type 2 design, type 1 transition, at sta 10+90. Q = 16,000 cfs

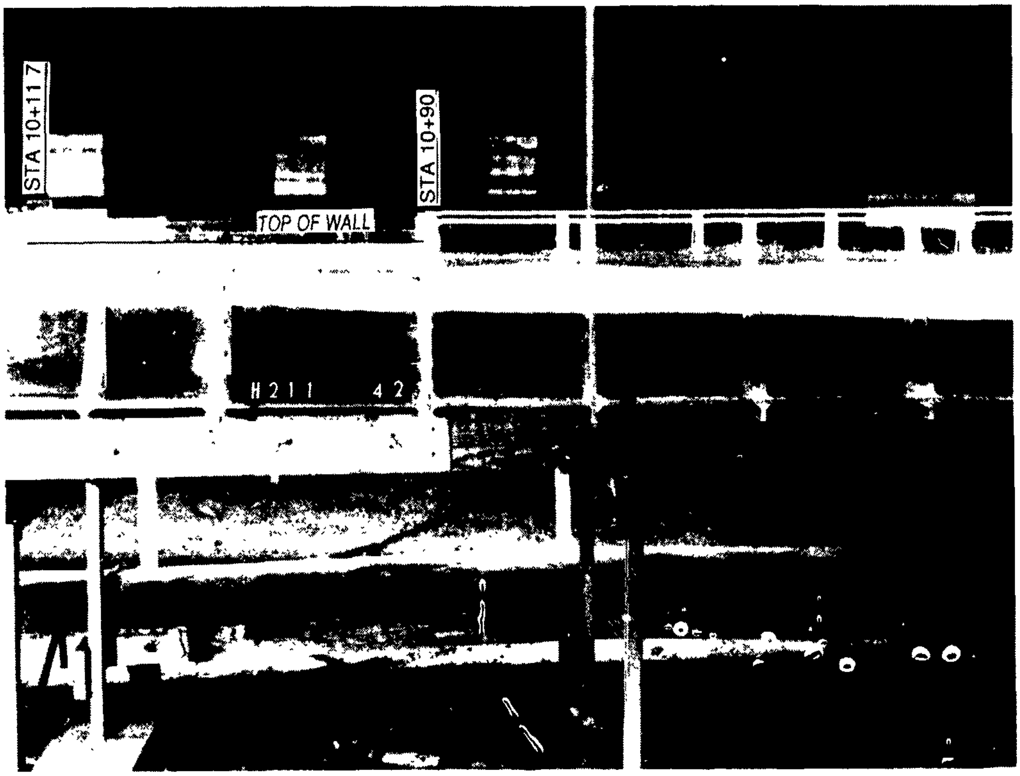



Photo 22. Side view of flow conditions in type 2 design, type 2 transition at sta 10+90. Q = 16,000 cfs

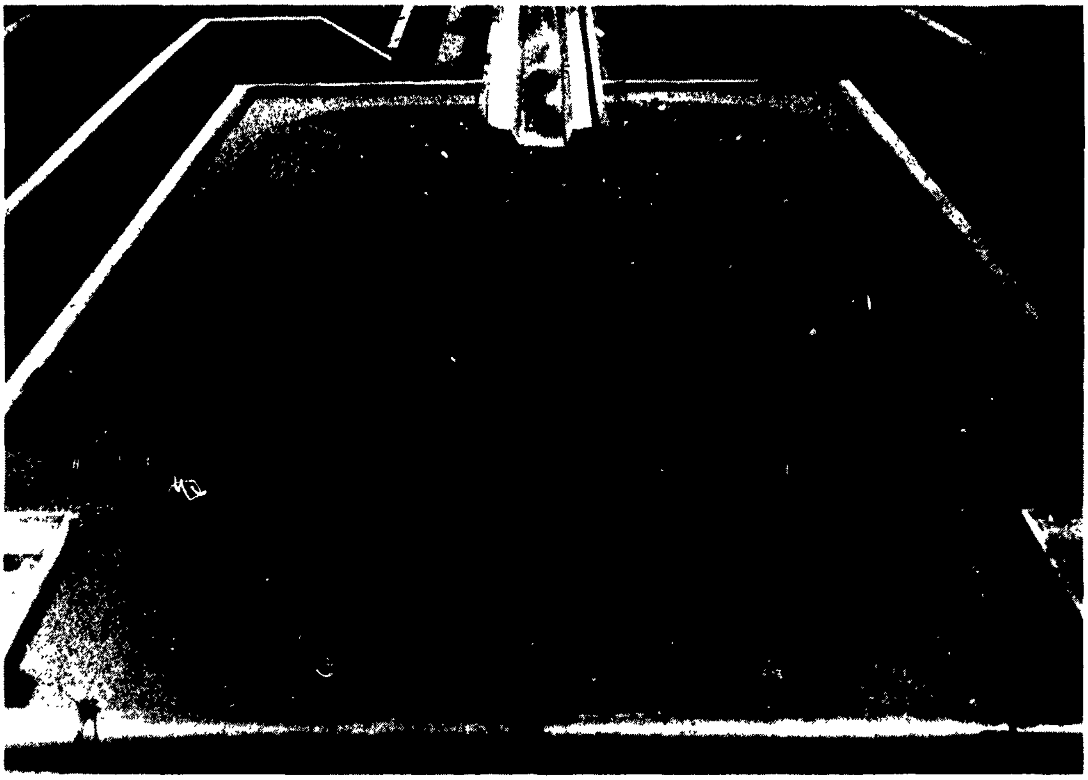
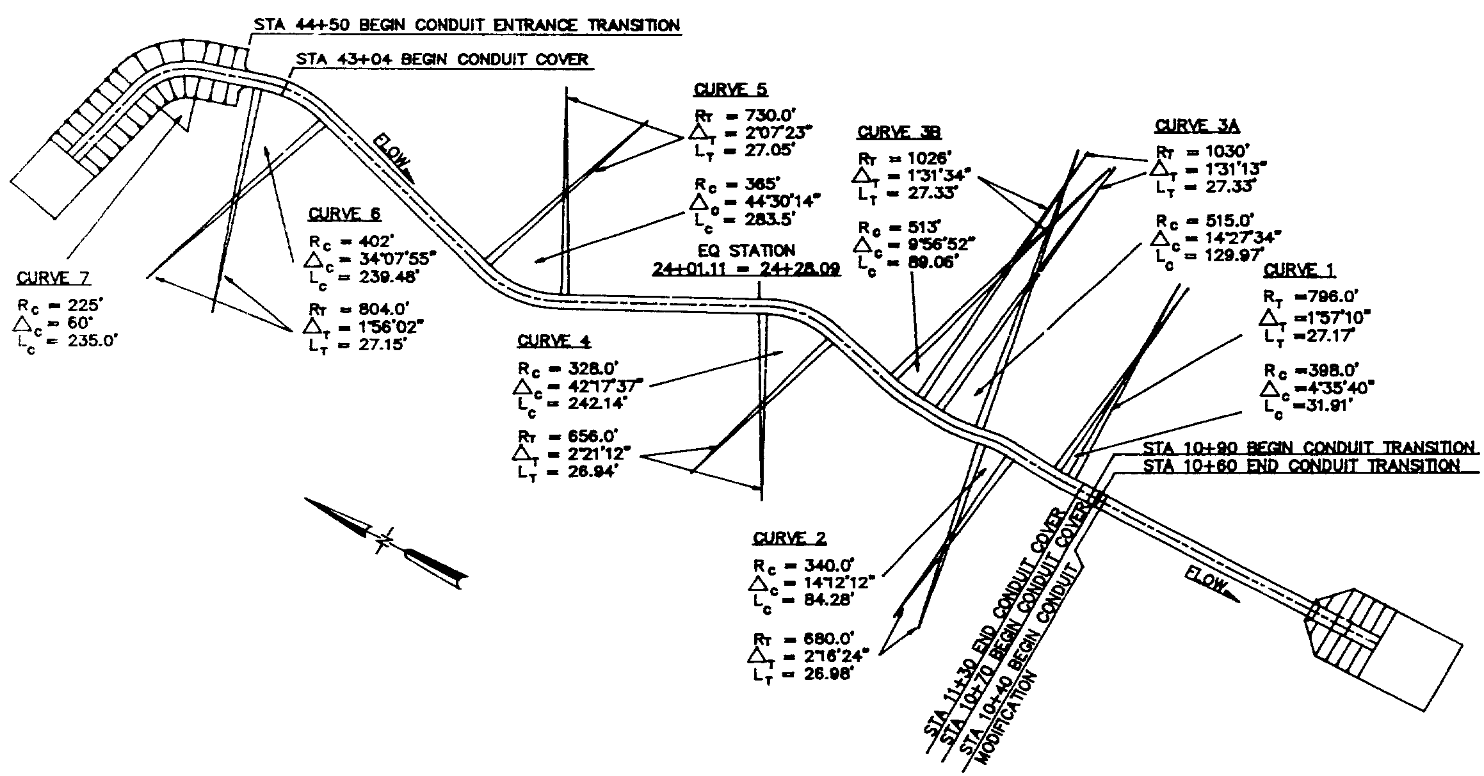


Photo 23. Dry bed view of exit channel with riprap basin, type 2 design




**PLAN VIEW**
**TYPE 1 (ORIGINAL) DESIGN**

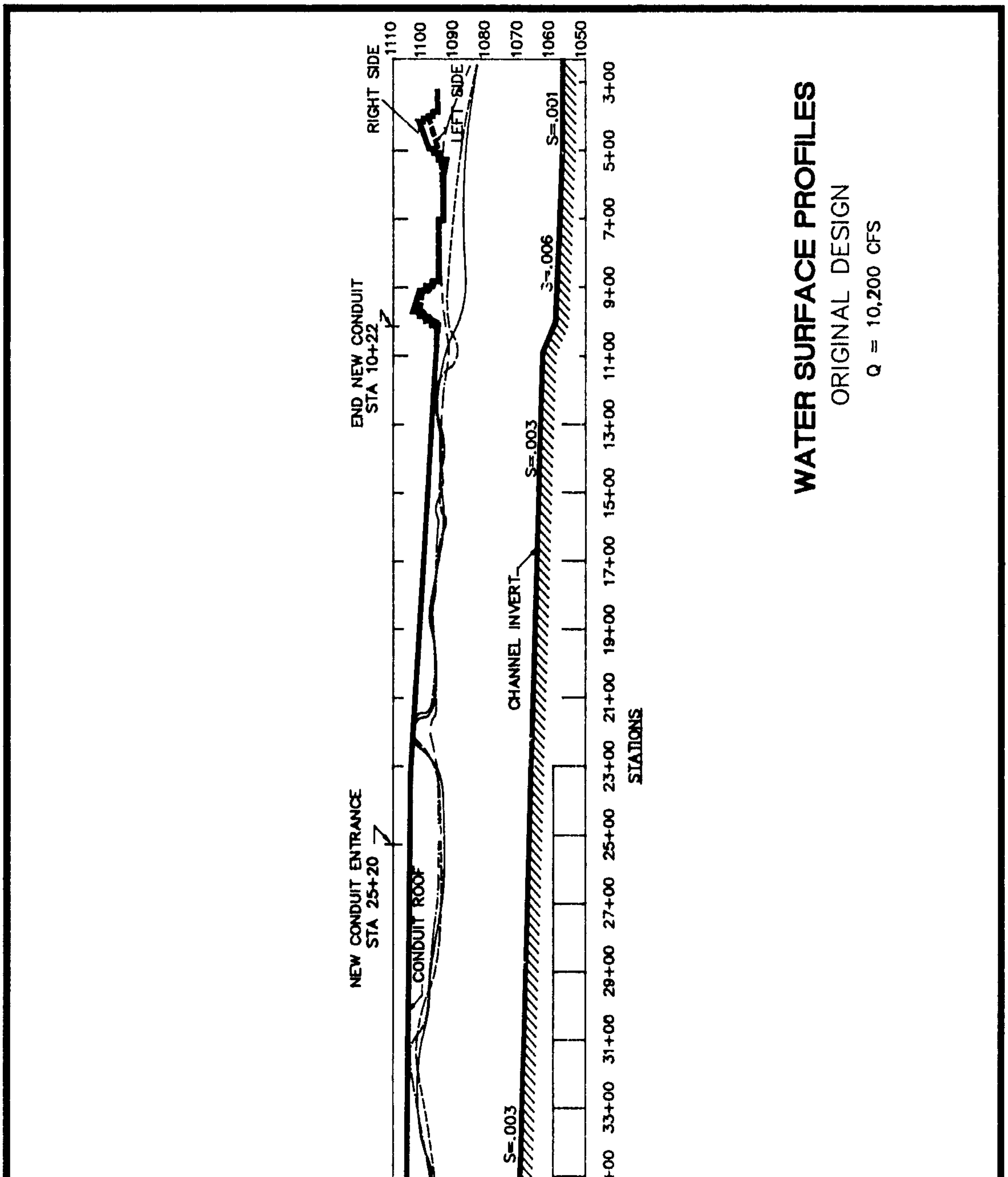
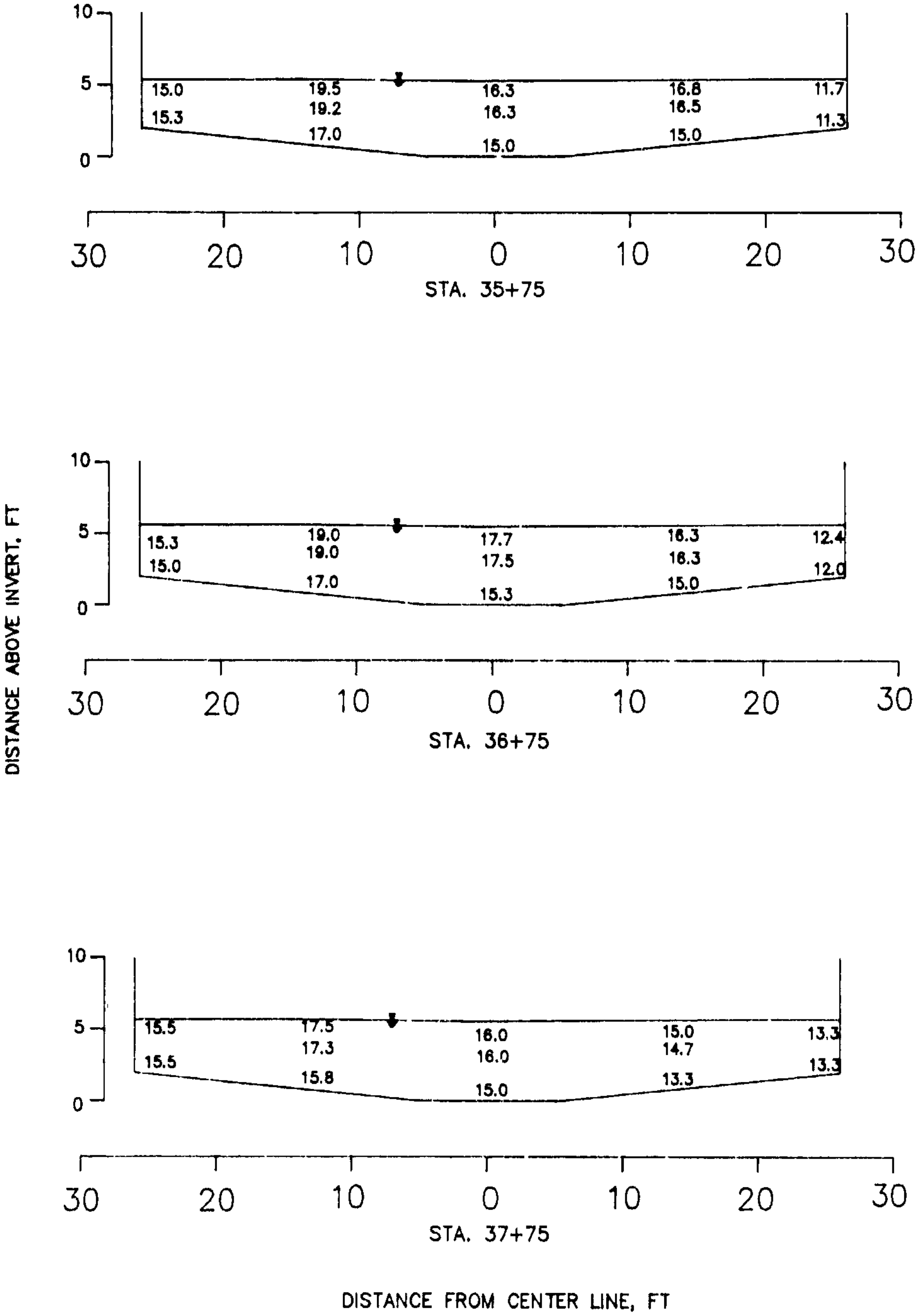

WATER SURFACE PROFILES
ORIGINAL DESIGN
Q = 10,200 CFS
ELEVATION FT, NGVD
STATIONS
EXISTING CONDUIT ENTRANCE
NEW CONDUIT ENTRANCE
STA 25+20
CONDUIT ROOF
END NEW CONDUIT
STA 10+22
RIGHT SIDE
LEFT SIDE
CHANNEL INVERT
CHANNEL INVERT
S=.003
S=.003
S=.006
S=.001
CENTER LINE
LEFT
RIGHT
1110
1100
1090
1080
1070
1060
1050
45+00
43+00
41+00
39+00
37+00
35+00
33+00
31+00
29+00
27+00
25+00
23+00
21+00
19+00
17+00
15+00
13+00
11+00
9+00
7+00
5+00
3+00

PLATE 2

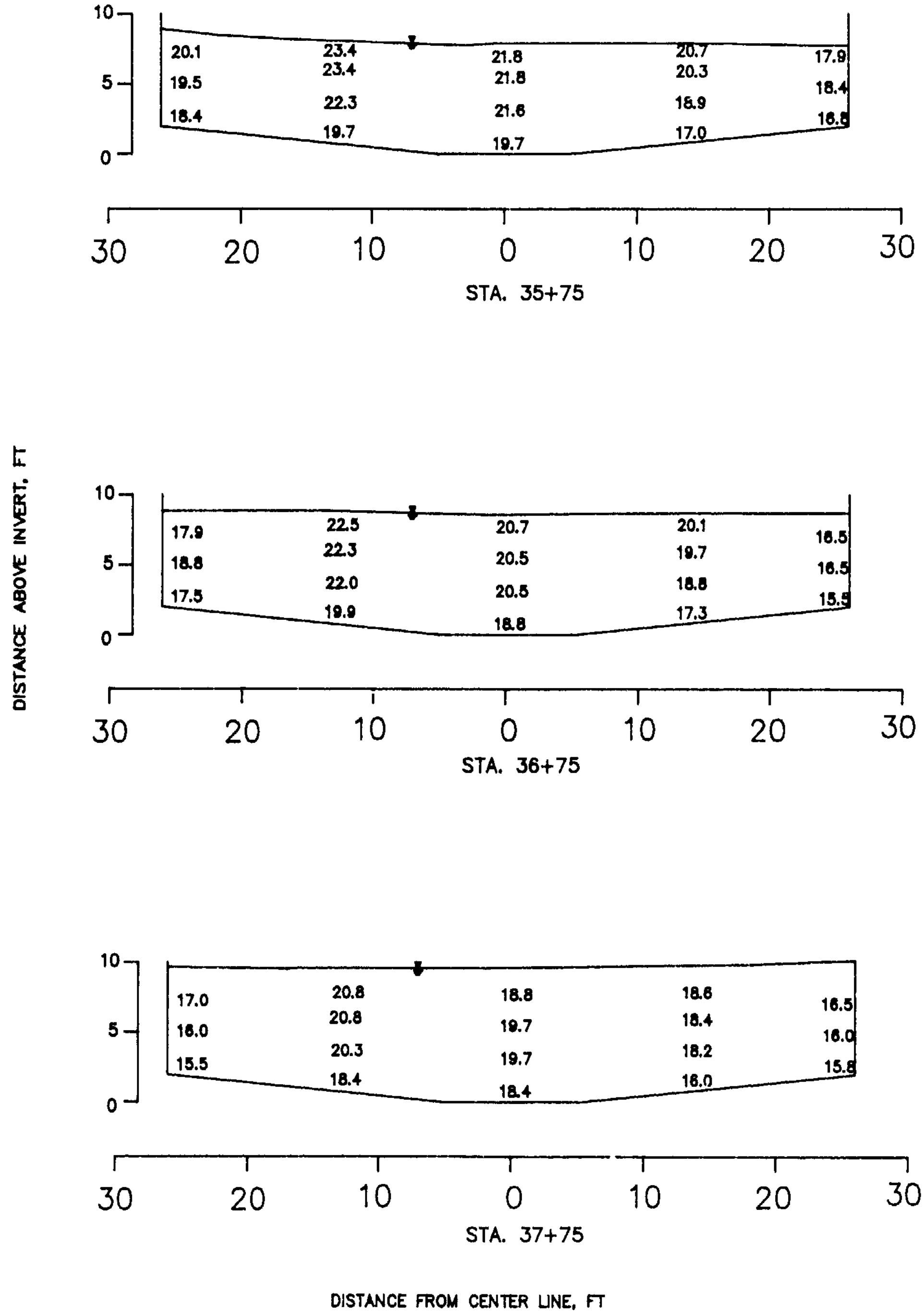



**MAXIMUM VELOCITIES, FPS**

ORIGINAL DESIGN

Q= 3,500 CFS

LOOKING DOWNSTREAM

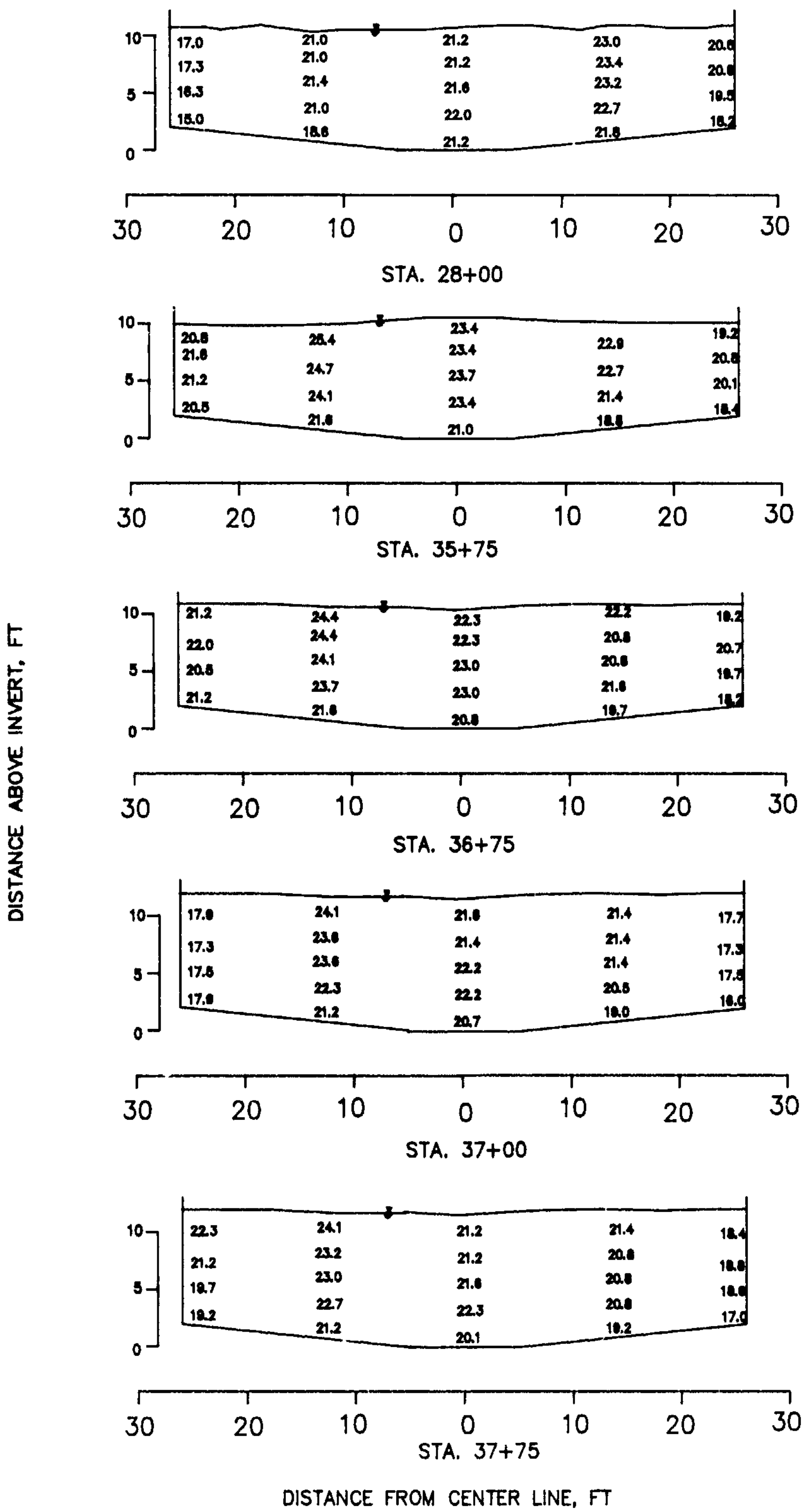



**MAXIMUM VELOCITIES, FPS**

ORIGINAL DESIGN

Q= 7,000 CFS

LOOKING DOWNSTREAM

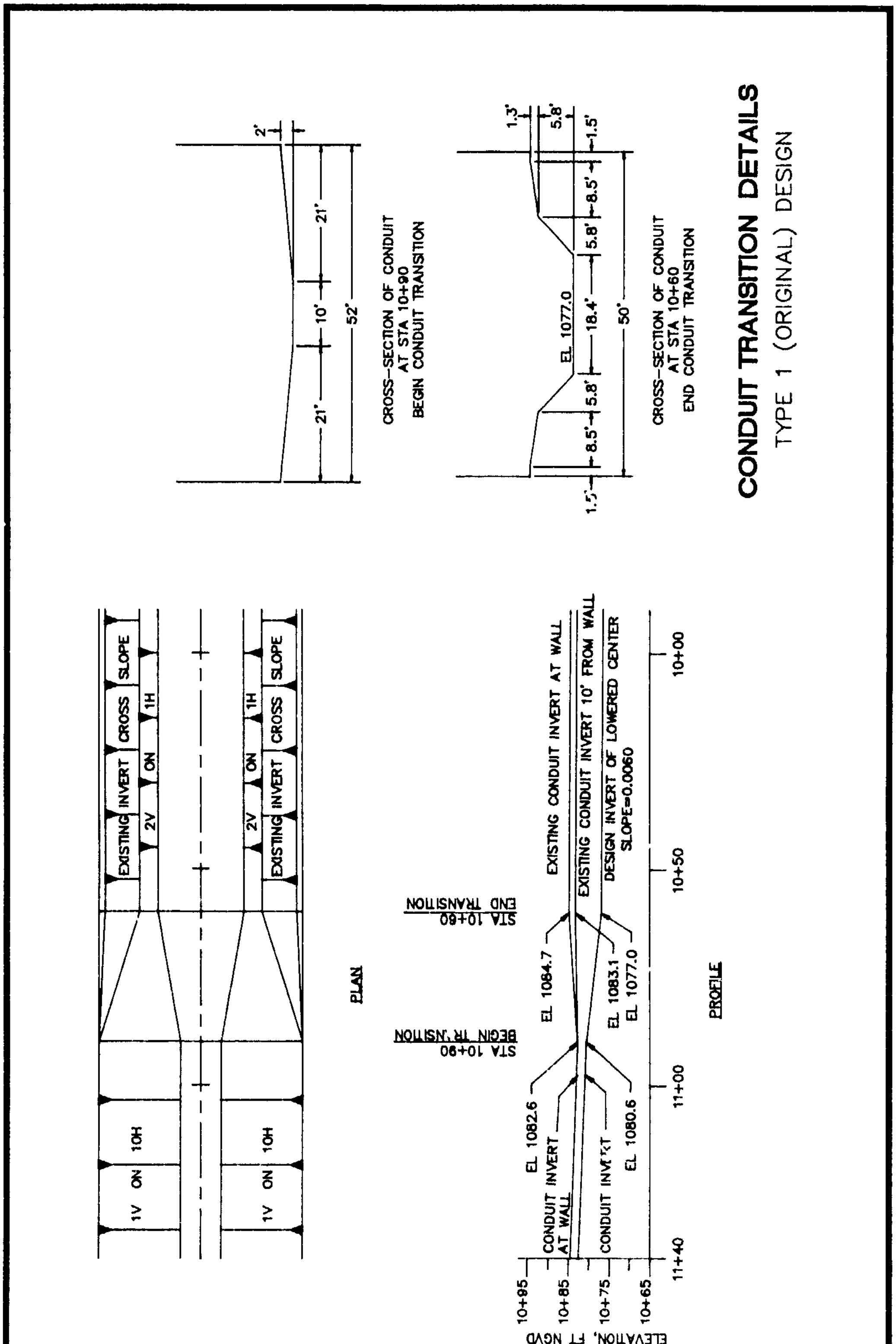



**MAXIMUM VELOCITIES, FPS**

ORIGINAL DESIGN

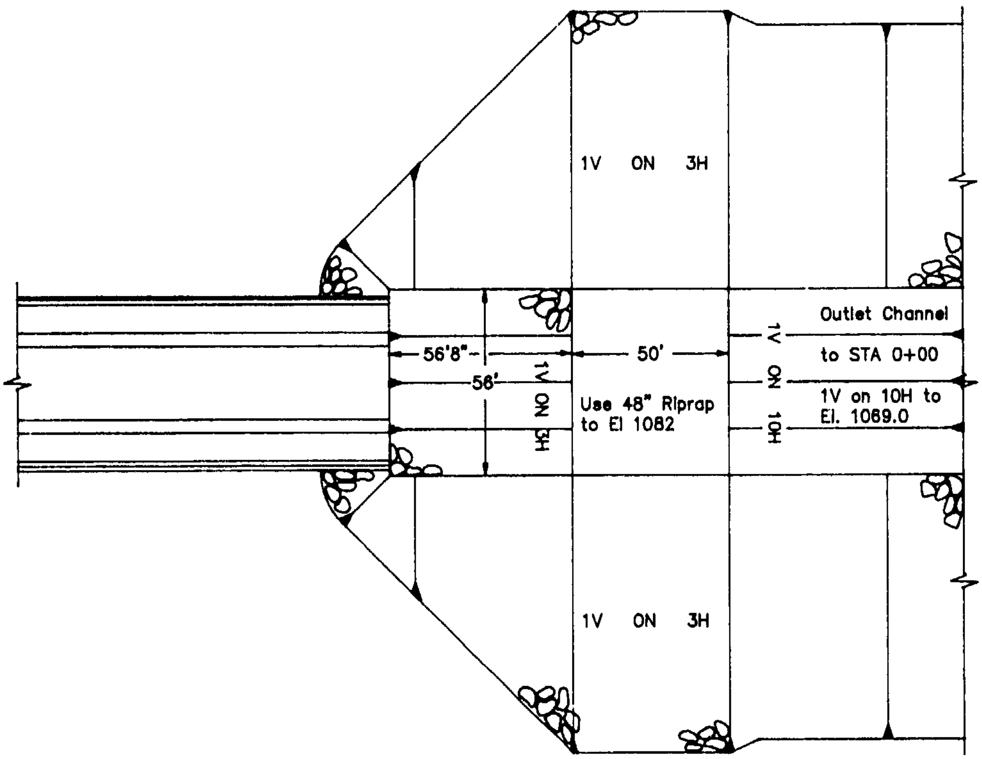
Q= 10,200 CFS

LOOKING DOWNSTREAM

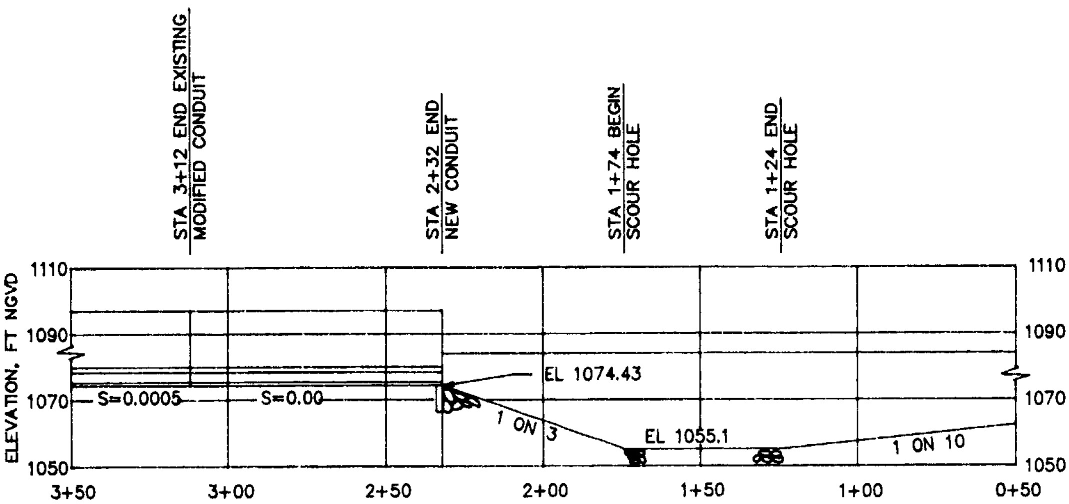


CONDUIT TRANSITION DETAILS
TYPE 1 (ORIGINAL) DESIGN
CROSS-SECTION OF CONDUIT AT STA 10+90 BEGIN CONDUIT TRANSITION
2'
21'
10'
21'
52'
CROSS-SECTION OF CONDUIT AT STA 10+60 END CONDUIT TRANSITION
1.3'
5.8'
1.5'
8.5'
5.8'
18.4'
5.8'
8.5'
1.5'
EL 1077.0
50'
PLAN
EXISTING INVERT 2V ON 1H CROSS SLOPE
1V ON 10H
STA 10+90 BEGIN TRANSITION
STA 10+60 END TRANSITION
PROFILE
EXISTING CONDUIT INVERT AT WALL
EXISTING CONDUIT INVERT 10' FROM WALL
DESIGN INVERT OF LOWERED CENTER SLOPE=0.0060
CONDUIT INVERT AT WALL
CONDUIT INVERT
EL 1082.6
EL 1080.6
EL 1084.7
EL 1083.1
EL 1077.0
ELEVATION, FT NGVD
10+95
10+85
10+75
10+65
11+40
11+00
10+50
10+00


PLATE 6



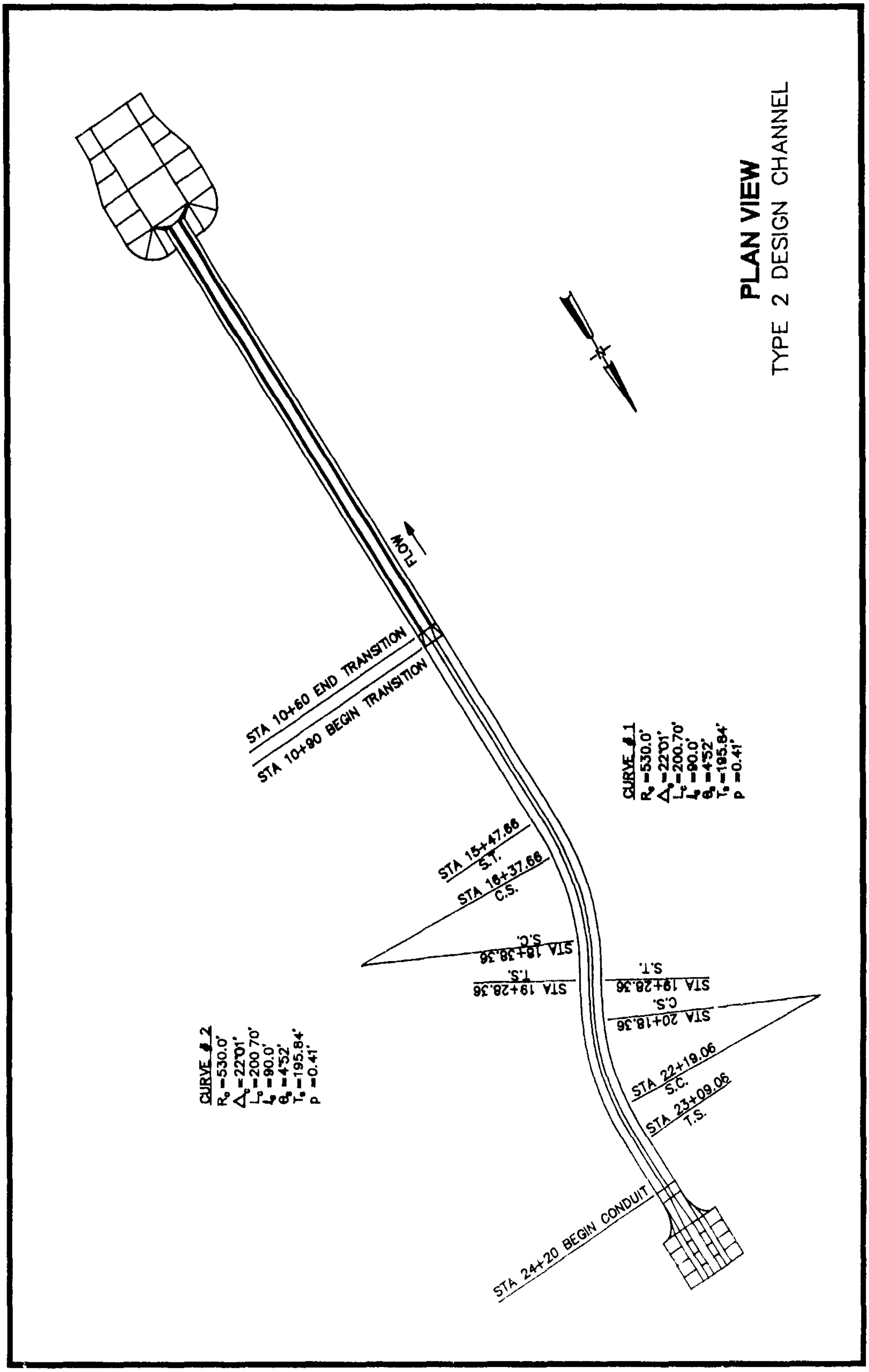

PLAN




PROFILE

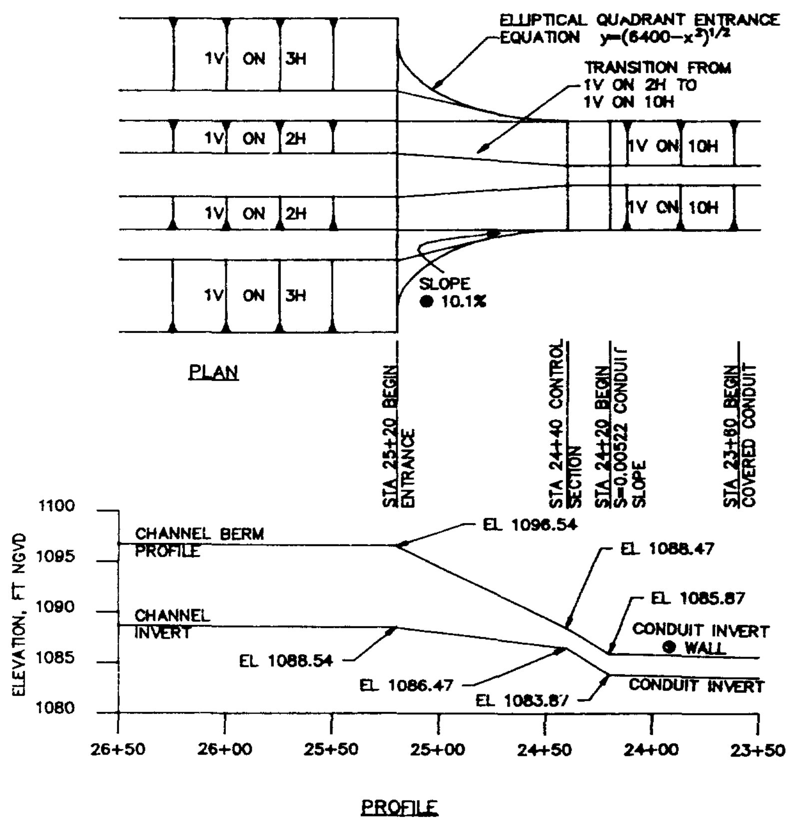
**EXIT CHANNEL AND SCOUR HOLE DETAILS**

ORIGINAL DESIGN



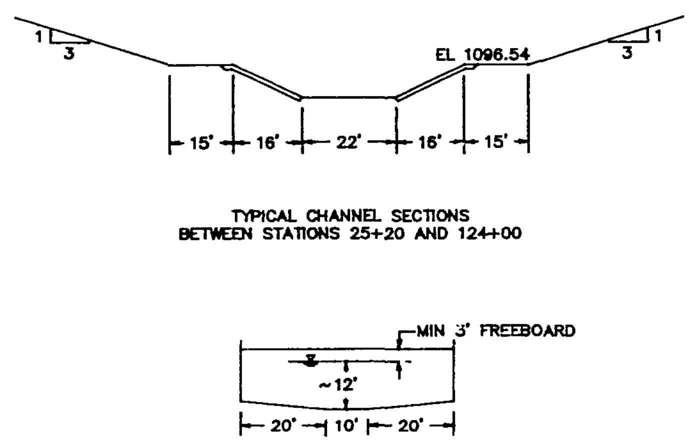
PLAN VIEW
TYPE 2 DESIGN CHANNEL
FLOW
STA 10+60 END TRANSITION
STA 10+90 BEGIN TRANSITION
CURVE # 1
$R_c$ =530.0'
$\Delta_c$ =22°01'
$L_c$ =200.70'
$L_s$ =90.0'
$\theta_s$ =4°52'
$T_s$ =195.84'
p =0.41'
STA 15+47.66
S.T.
STA 16+37.66
C.S.
STA 18+18.36
S.C.
STA 19+28.36
T.S.
STA 19+28.36
S.T.
STA 20+18.36
C.S.
STA 22+19.06
S.C.
STA 23+09.06
T.S.
CURVE # 2
$R_c$ =530.0'
$\Delta_c$ =22°01'
$L_c$ =200 70'
$L_s$ =90.0'
$\theta_s$ =4°52'
$T_s$ =195.84'
p =0.41'
STA 24+20 BEGIN CONDUIT


PLATE 8




PLAN

PROFILE

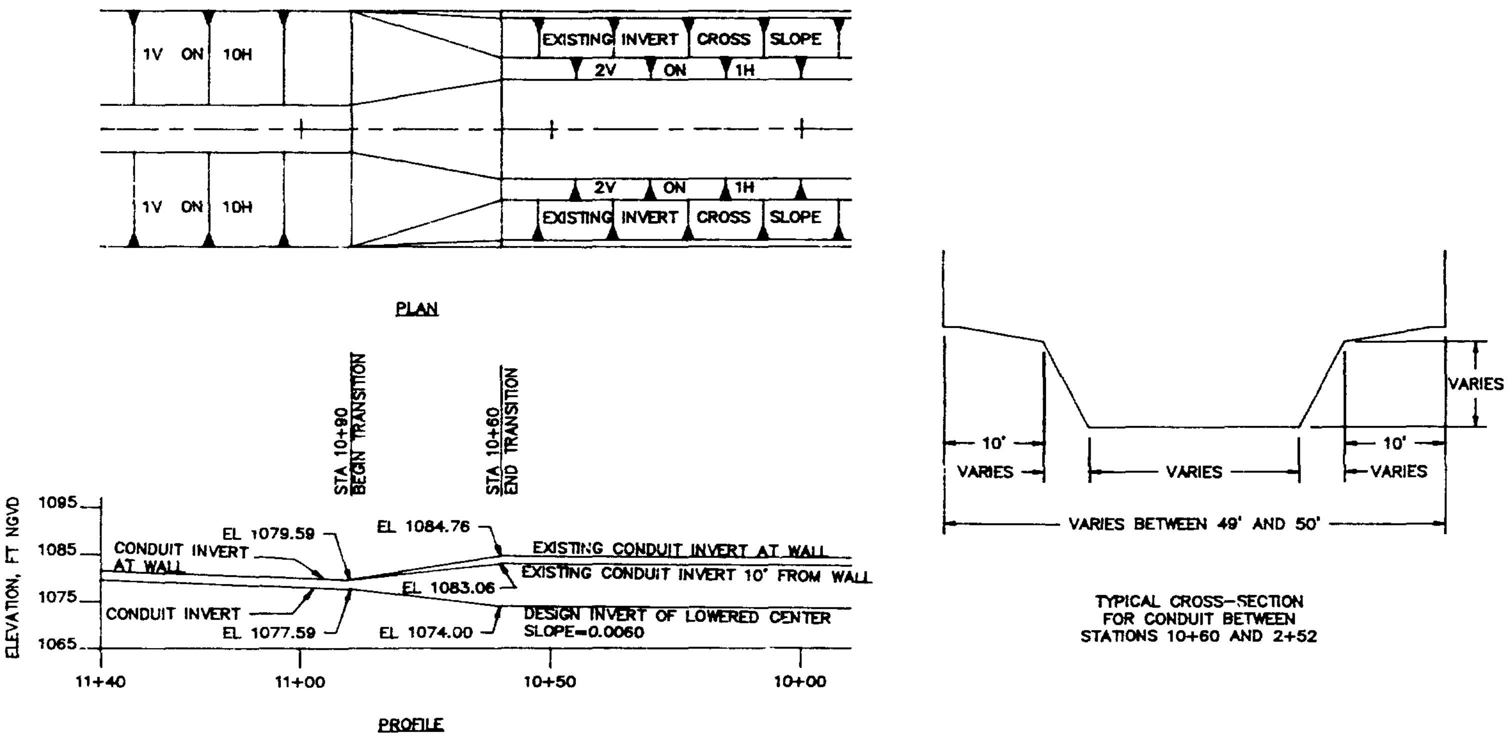



TYPICAL CHANNEL SECTIONS
BETWEEN STATIONS 25+20 AND 124+00

TYPICAL CROSS-SECTION
FOR CONDUIT BETWEEN
STATIONS 10+90 AND 24+20

**APPROACH CHANNEL, APPROACH CHANNEL TRANSITION, AND CONDUIT**

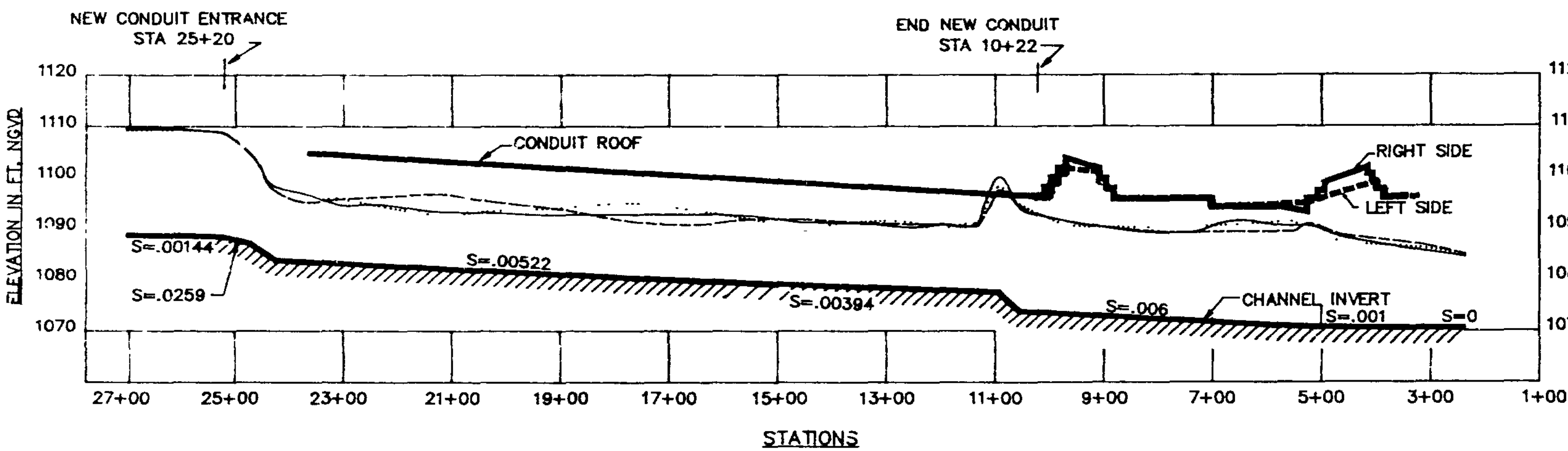
PLAN, PROFILE, AND SECTIONS
TYPE 2 DESIGN CHANNEL




**TYPE 1 (ORIGINAL) DESIGN CONDUIT TRANSITION**

PLAN, PROFILE, AND SECTION VIEWS

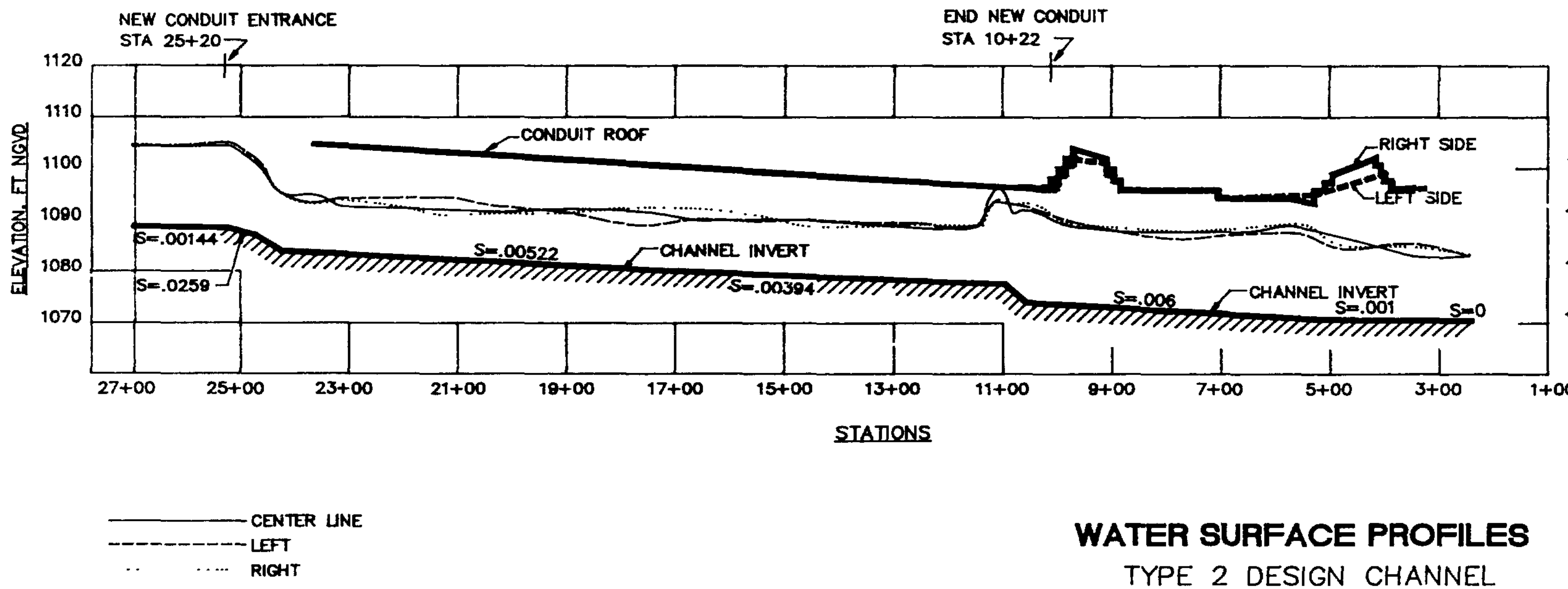
TYPE 2 DESIGN CHANNEL




**WATER SURFACE PROFILES**

TYPE 2 DESIGN CHANNEL

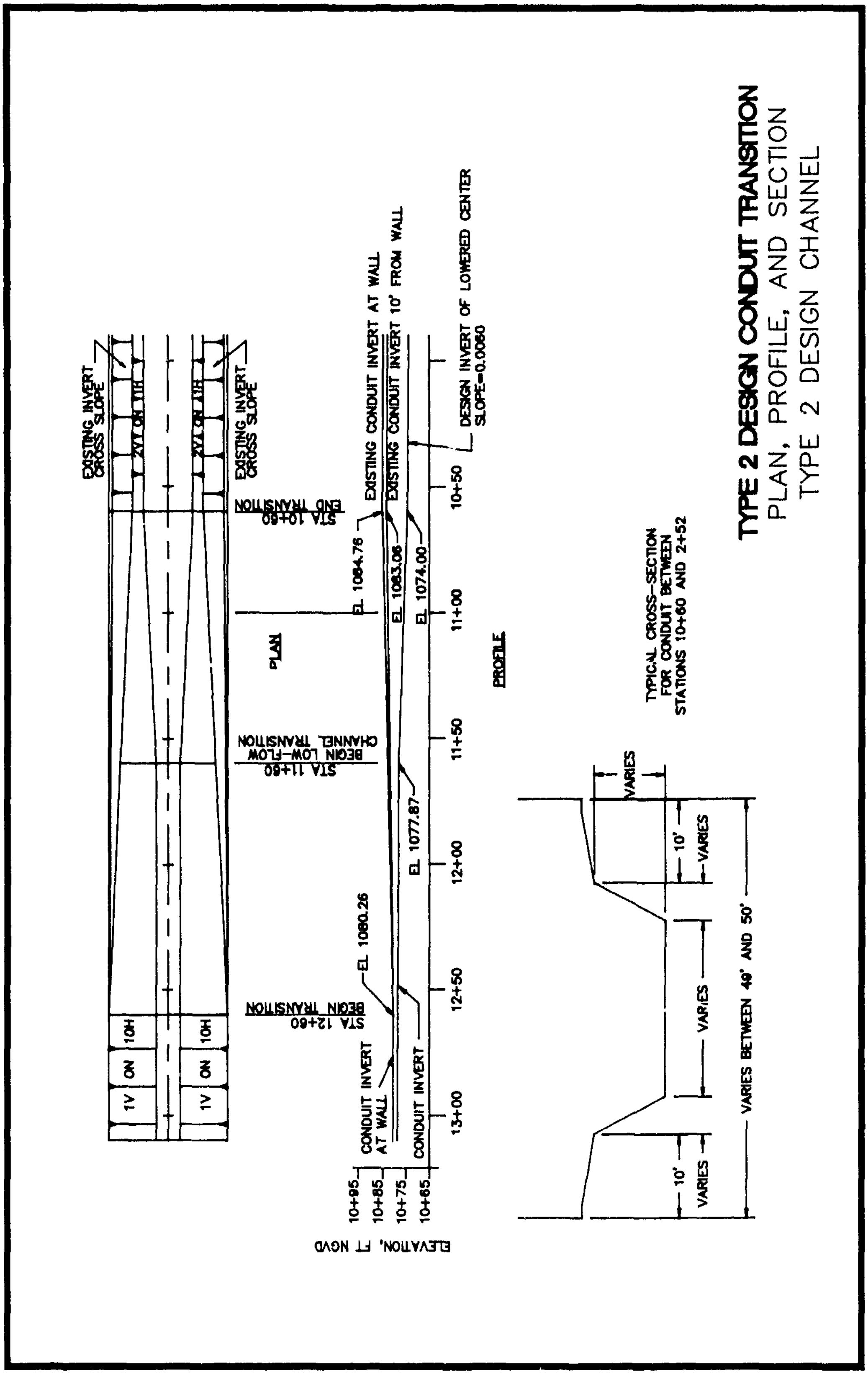
Q = 16,000 CFS




**WATER SURFACE PROFILES**

TYPE 2 DESIGN CHANNEL

Q = 10,200 CFS


TYPE 2 DESIGN CONDUIT TRANSITION
PLAN, PROFILE, AND SECTION
TYPE 2 DESIGN CHANNEL
EXISTING INVERT CROSS SLOPE
2V:1 ON 1H
1V ON 10H
STA 10+60 END TRANSITION
STA 11+60 BEGIN LOW-FLOW CHANNEL TRANSITION
STA 12+60 BEGIN TRANSITION
PLAN
EXISTING CONDUIT INVERT AT WALL
EXISTING CONDUIT INVERT 10' FROM WALL
DESIGN INVERT OF LOWERED CENTER
SLOPE=0.0060
EL 1084.76
EL 1083.06
EL 1074.00
EL 1077.87
EL 1080.26
CONDUIT INVERT AT WALL
CONDUIT INVERT
10+50
11+00
11+50
12+00
12+50
13+00
10+95
10+85
10+75
10+65
ELEVATION, FT NGVD
PROFILE
TYPICAL CROSS-SECTION FOR CONDUIT BETWEEN STATIONS 10+60 AND 2+52
VARIES
10'
VARIES BETWEEN 49' AND 50'

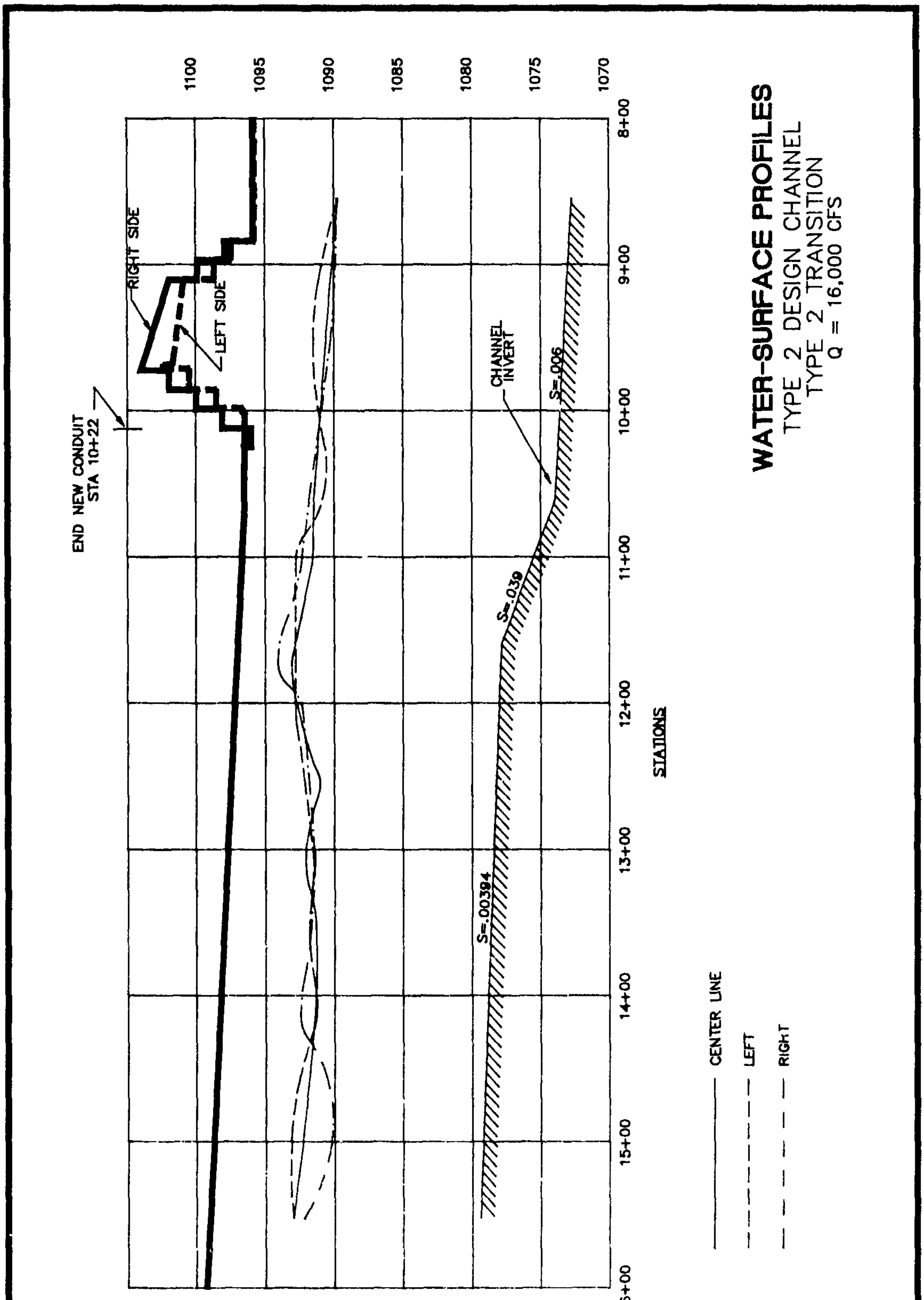
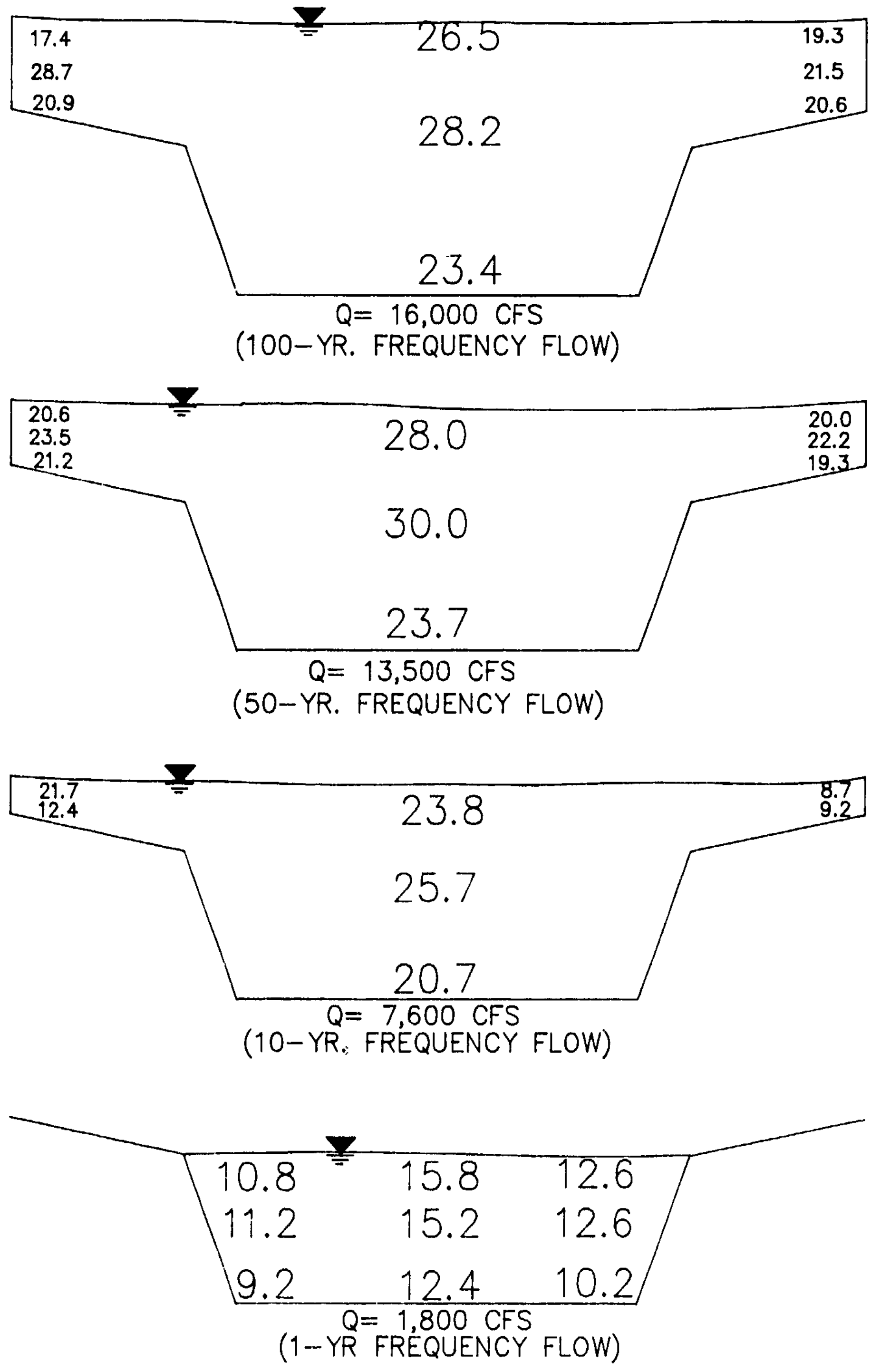

WATER-SURFACE PROFILES
TYPE 2 DESIGN CHANNEL
TYPE 2 TRANSITION
Q = 16,000 CFS
END NEW CONDUIT
STA 10+22
RIGHT SIDE
LEFT SIDE
CHANNEL
INVERT
S=.006
S=.039
S=.00394
ELEVATION, FT NGVD
STATIONS
8+00
9+00
10+00
11+00
12+00
13+00
14+00
15+00
16+00
1100
1095
1090
1085
1080
1075
1070
CENTER LINE
LEFT
RIGHT

PLATE 14



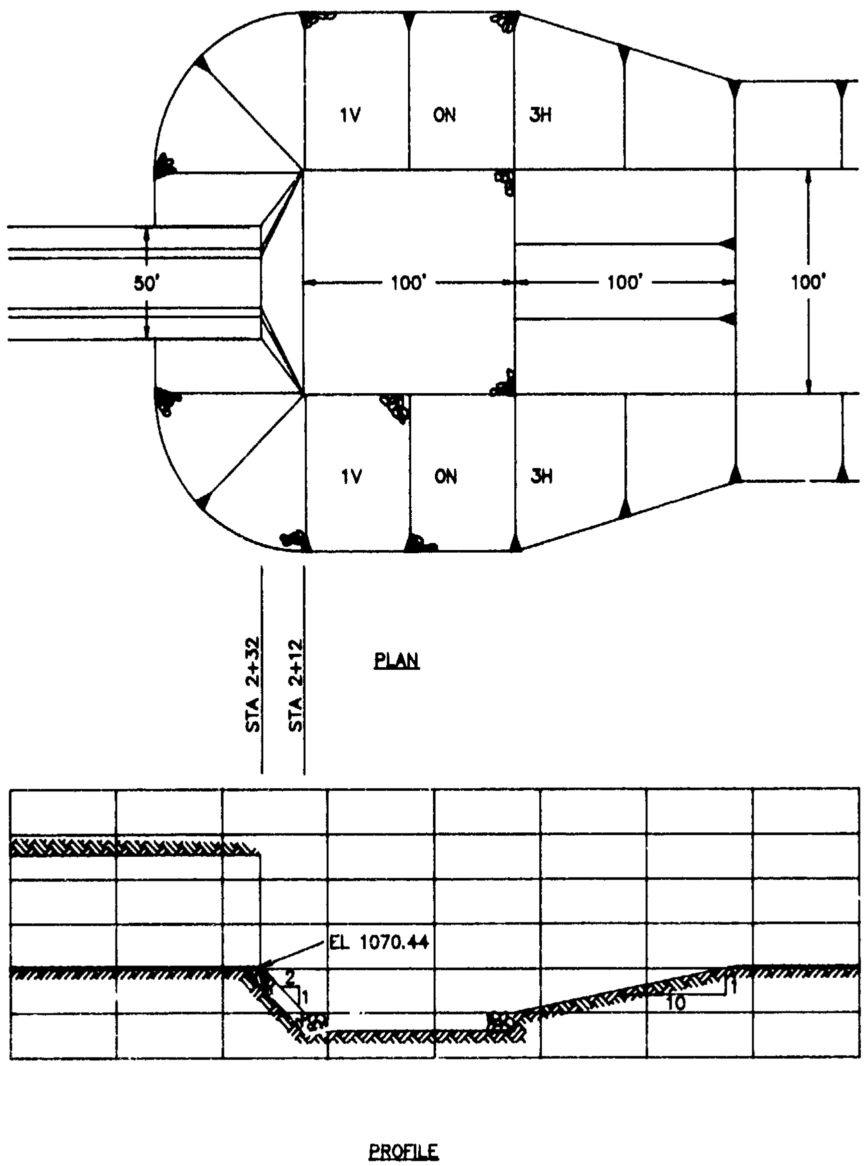

**MAXIMUM VELOCITIES, FPS**

TYPE 2 CHANNEL

TYPE 2 TRANSITION

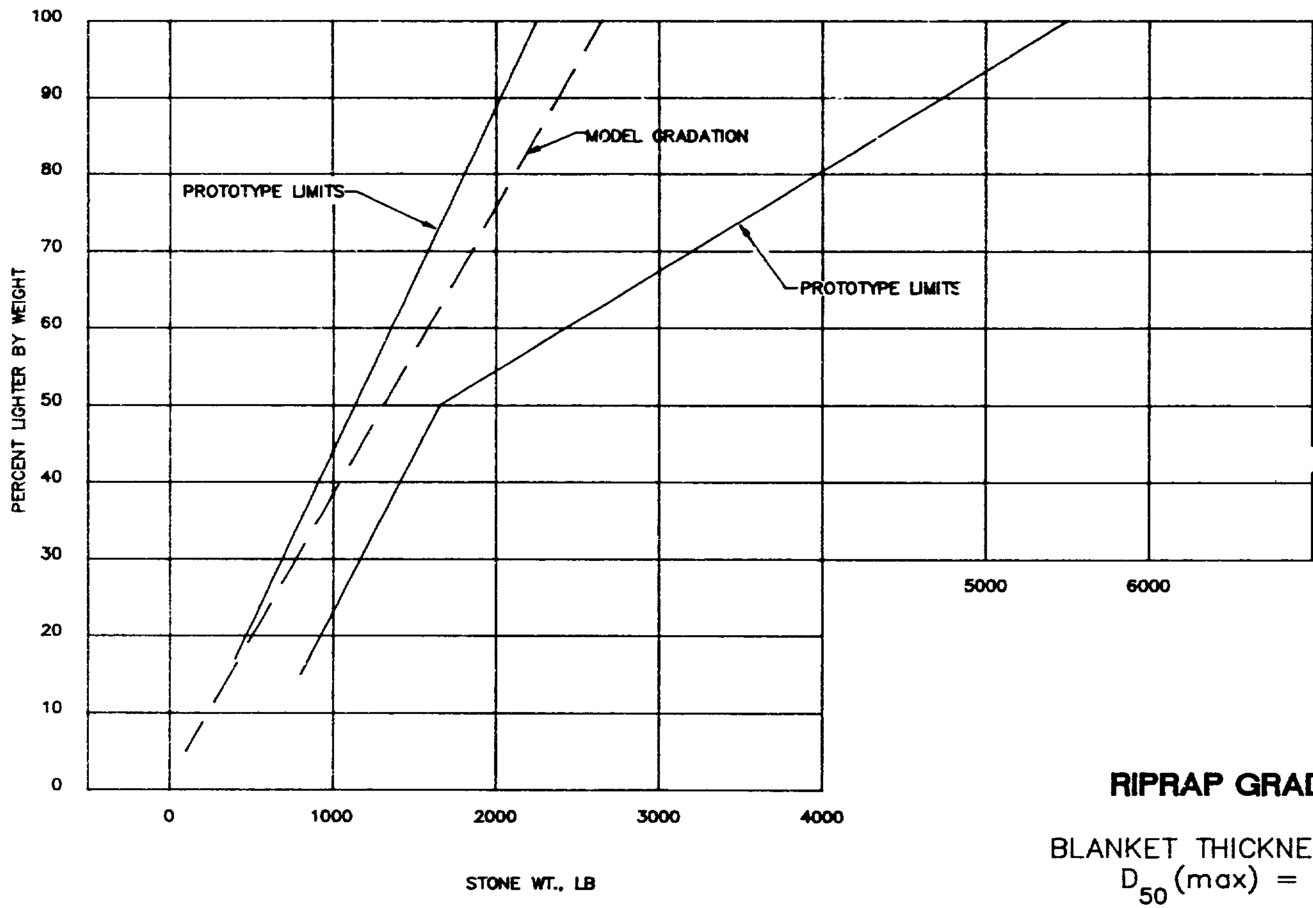
STA. 2+32

LOOKING DOWNSTREAM



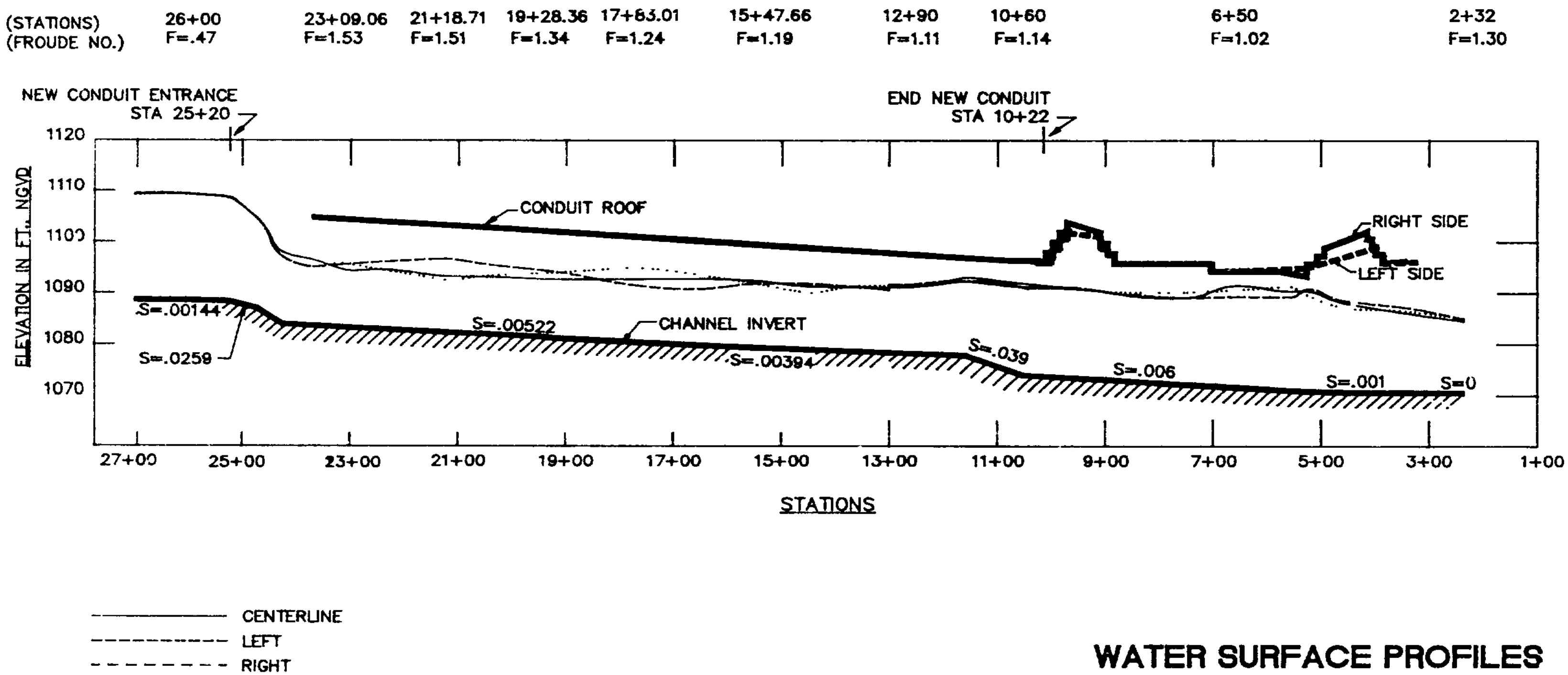

**RIPRAP SCOUR HOLE AND EXIT CHANNEL**

PLAN AND PROFILE




**RIPRAP GRADATION**

BLANKET THICKNESS = 4 FT
$D_{50}$(max) = 2.7 ft




**WATER SURFACE PROFILES**
RECOMMENDED DESIGN
TYPE 2 DESIGN CHANNEL
TYPE 2 TRANSITION
Q = 16,000 CFS