



TECHNICAL REPORT H-75-3

WAIMANO STREAM FLOOD CONTROL PROJECT, PEARL CITY, HAWAII

Hydraulic Model Investigation

by

Peter E. Saunders

Hydraulics Laboratory

U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Honolulu, Hawaii

U.S.C.E.C.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Tests were conducted on an undistorted, 1:20-scale physical model of the high-velocity channel for Waimano Stream to determine the adequacy of the sinuous channel to pass discharges as large as 6300 cfs. Since right-of-way limitations prevented major realignment of the proposed channel, superelevated curves were more severe than those recommended by current design guidance. The entering transition section was modified to improve flow conditions. (Continued)		

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20. ABSTRACT (Continued).

Also, the superelevation was increased and the curve design modified in several locations to improve flow distribution. The Moanalua Road drains were modified to improve flow conditions at their confluence with the main channel and the entrances to the relief drain and the diversion channel were modified to facilitate passage of the required flows.

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PREFACE

The hydraulic model study of the high-velocity channel for Waimano Stream reported herein was authorized by the Office, Chief of Engineers, on 29 March 1972, at the request of the U. S. Army Engineer Division, Pacific Ocean (POD).

The study was conducted during the period April 1972-November 1973, in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Messrs. T. E. Murphy and J. L. Grace, Jr., former and current Chiefs, respectively, of the Structures Division, and under the general supervision of Mr. Grace, former Chief of the Spillways and Channels Branch. The engineers in immediate charge of the model were Messrs. E. S. Melsheimer and P. E. Saunders, assisted by Messrs. B. Perkins and W. A. Walker. This report was prepared by Mr. Saunders.

During the course of the study, Messrs. H. Kobayashi, C. Lee, and H. Young of the POD visited the WES to discuss the program of model tests, observe the model in operation, and correlate test results with the concurrent design work.

Directors of the WES during the conduct of this study and the preparation and publication of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO
METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square miles	2.58999	square kilometers
feet per second	0.3048	meters per second
cubic feet per second	0.02832	cubic meters per second



Figure 1. Location map

WAIMANO STREAM FLOOD CONTROL PROJECT

PEARL CITY, HAWAII

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The proposed Waimano Stream flood control project will be located on the southern coast of the island of Oahu, about 9 miles* northwest of downtown Honolulu (Figure 1). Waimano Stream has a drainage area of approximately 2.6 square miles.

2. A high-velocity chute will extend 3570 ft, from the Momilani subdivision to the county relief drain intake area. Under project conditions, the design flood will produce discharges of 4800 cfs above and 6300 cfs below the confluence of Waimano Stream and the Moanalua Road drains. The relief drain intake, located below the Moanalua drains, is designed to divert enough flow from the proposed high-velocity chute to eliminate the need for improving the existing channel downstream of the proposed project limits.

3. The upstream portion of the proposed chute will involve a transition from a trapezoidal section with a base width of 30 ft and 1V on 1H side slopes to a rectangular section 17 ft wide.

Purpose of the Model Study

4. Several of the superelevated curves in the proposed chute could not be designed within the limits of established design criteria because of economic restrictions requiring adherence to the existing channel right-of-way. Because of the difficulty involved in the design

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

of this project, model analysis was desired in the interests of economy, performance, and good engineering practice. The model investigation was particularly concerned with the trapezoidal to rectangular transition, the superelevation requirements in various curves, the area adjacent to the entering Moanalua Road drains, and the division of flow in the vicinity of the relief drain.

PART II: THE MODEL

Description

5. The model of the high-velocity chute section of Waimano Stream (Figure 2) was constructed to an undistorted linear scale ratio of 1:20 and reproduced a channel length of 3570 ft, from the trapezoidal to rectangular transition at the upstream limit of the project to the downstream relief drain. The channel bottom of curved sections and the walls of the transition section were molded of cement mortar to sheet metal templates. The channel bottom in tangent sections and the frame supporting the channel were constructed of plywood and painted with enamel paint to lower hydraulic resistance and Manning's n value.* The sides of the channel were made of sheet metal, and the entering box culverts were fabricated of plastic. The model was supported with a framework of steel angles.

6. Water used in the operation of the model was supplied by pumps. Entering discharges were measured with venturi meters, and exit discharges were measured with a sharp-edged weir. Water-surface elevations and velocities were measured with point gages and Pitot tubes, respectively. The tops of the model sidewalls were set 1 ft above the original channel bottom elevation to provide adequate freeboard and a reference elevation for measuring devices.

Interpretation of Model Results

7. The accepted equations of hydraulic similitude, based upon Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations are as follows:

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix B).

Figure 2. Model of high-velocity chute section of Waimano Stream



<u>Characteristic</u>	<u>Dimension*</u>	<u>Model:Prototype Scale Relation</u>
Length	L	$L_r = 1:20$
Area	L^2	$A_r = L_r^2 = 1:400$
Velocity	$L^{1/2}$	$V_r = L_r^{1/2} = 1:4.47$
Discharge	$L^{5/2}$	$Q_r = L_r^{5/2} = 1:1789$
Manning's n	$L^{1/6}$	$n_r = L_r^{1/6} = 1:1.648$

* Dimensions are in terms of length.

Measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively from the model to prototype by means of the above scale relations.

PART III: TESTS AND RESULTS

Entering Transition

8. The upstream portion of the Waimano Stream project will contain a transition from a trapezoidal channel with a 30-ft bottom width and 1V on 1H side slopes to a 17-ft-wide rectangular section. The original design consisted of a transition from the trapezoidal section to a 20-ft-wide rectangular section in a distance of 100 ft. This section was maintained for another 100 ft before decreasing to the 17-ft-wide section in a distance of 30 ft. The center lines of the trapezoidal and rectangular channels were offset, and most of the decrease in channel width occurred on the right side of the channel (Plate 1).

9. Test results for the original transition indicated that a transverse wave was generated (Photo 1a) which adversely affected the flow conditions in curve 1. Elimination of the 20-ft-wide rectangular section increased the height of the transverse wave. Transitions of increased length were investigated and found to be effective in eliminating the transverse wave. The recommended transition (Plate 2) is provided in 200 ft along the left wall and 240 ft along the right wall and changes directly from the 30-ft-wide trapezoidal section to the 17-ft-wide rectangular section. Flow conditions with this design are shown in Photo 1b.

Superelevation and Constrictions

10. Model investigation of the original design indicated that curves 1 and 3-5 (Figure 3) needed modification to improve the flow distribution. The original design of curve 1 consisted of two spirals with a maximum superelevation of 6 ft occurring at the midpoint of the curve (Plates 3 and 4). This superelevation was rotated about the center line of the channel. Model tests indicated the need for increased superelevation, which was rotated about the inside of the curve in order to maintain free drainage with the increased superelevation. The

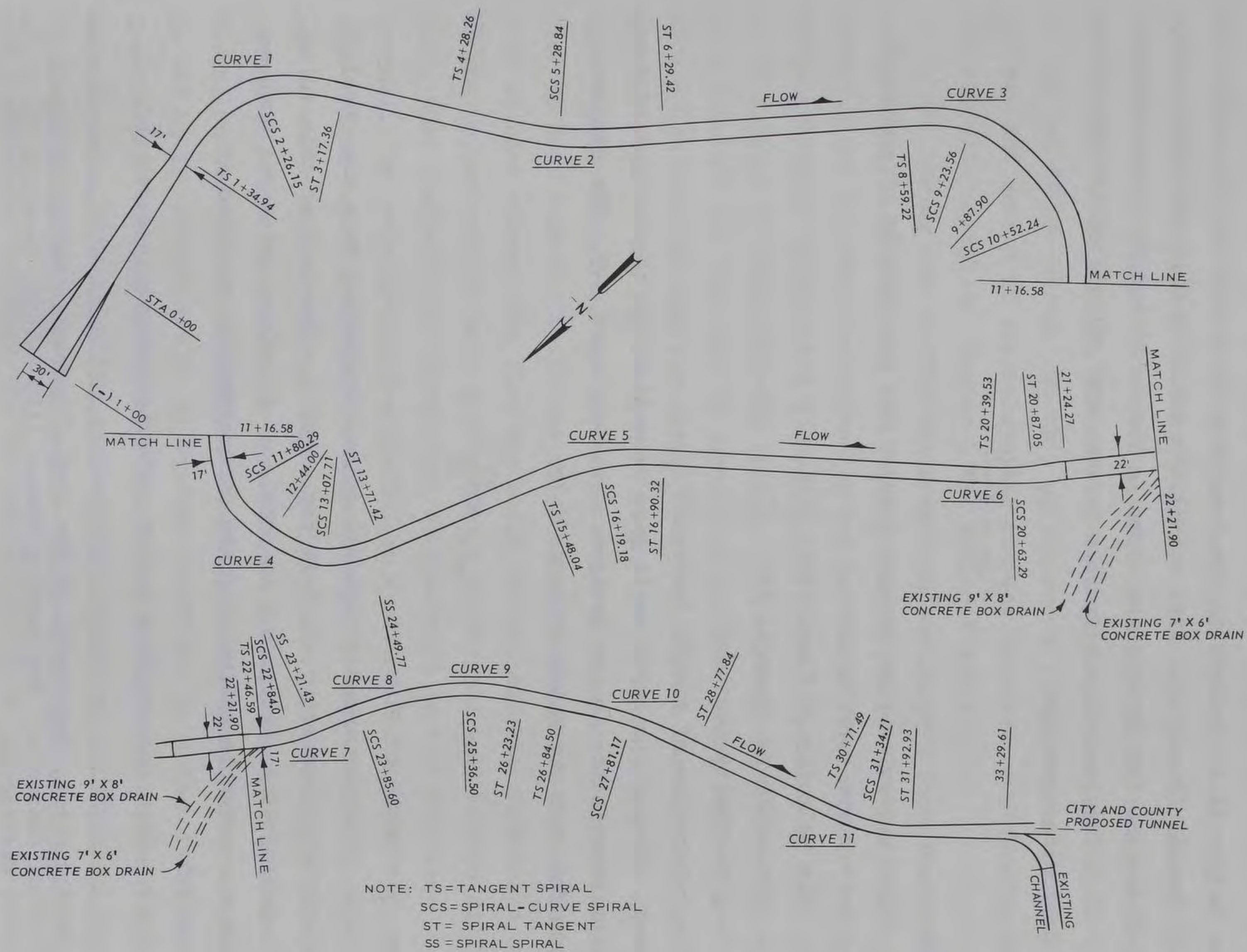


Figure 3. General plan of project

recommended design has a superelevation that rises through the first 30 percent of the curve (60 percent of the length of the entering spiral) to a maximum of 8 ft and is maintained for the next 40 percent of the curve before it is reduced in the remaining 30 percent of the curve to a level channel (Plate 4). Flow conditions with the original and recommended designs for curve 1 are shown in Photos 2a and 2b, respectively.

11. Original superelevation values were calculated through use of the following equation:

$$\Delta y = \frac{cV^2W}{gr} \quad (1)*$$

where

Δy = superelevation between center line and outside of curve, ft

c = curve coefficient

V = velocity of flow, fps

W = width of channel, ft

g = gravity constant

r = radius of simple curve, ft

However, most of the curve radii were less than the theoretical minimum, causing uncertainty in the designs of curves 1 and 3-5. The minimum radius for each curve was determined by

$$r_{\min} = \frac{4V^2W}{gy} \quad (2)**$$

where y = depth of flow, ft.

12. The recommended superelevation, determined from the physical model by trial and error, is 8 ft for curve 1. One-half of this value was substituted in Equation 1 to obtain a c value, which was used to obtain a reasonable estimate of the superelevation required in curves 3-5.

13. With the original design, adverse transverse waves and

* Headquarters, Department of the Army, "Hydraulic Design of Flood Control Channels," Engineering Manual 1110-2-1601, Equation 26, 1 Jul 1970, Washington, D. C.

** Engineering Manual 1110-2-1601, op. cit., Equation 28.

overtopping of the walls were experienced in the vicinity of curves 3 and 4 because of the tortuous curvature resulting from the right-of-way limitation (Photos 3a, 4a, 5a). Curve 3 (Figure 3) originally consisted of four spirals with a maximum superelevation of 4 ft occurring at the end of the first spiral (Plates 5 and 6). The superelevation was reduced to zero through the second spiral, returned to the maximum of 4 ft through the third spiral, and reduced through the fourth spiral to zero at the end of the curve. At this point, curve 4 began with the same pattern and amount of superelevation but was directed or deflected in the opposite direction (Figure 3 and Plates 6 and 7).

14. Using the coefficient developed for curve 1 from Equation 1, total superelevations of 9 and 9.5 ft, respectively, were indicated for curves 3 and 4. The superelevation was increased from zero to the total value indicated by Equation 1 through the first 15 percent of each curve, or 60 percent of each entering spiral. The maximum superelevation was held constant for the next 20 percent of curves 3 and 4 and was decreased to zero through the next 15 percent of each curve. This pattern was repeated in the second half of each curve (Plates 5 and 7). With this superelevation scheme there was still an unbalanced flow distribution in both curves. Thus, the total superelevation was increased by 2 ft in each curve. The flow was still uneven, and the amount and slope of the superelevation were approaching a point that would prove difficult, uneconomical, and impractical to construct in the prototype channel. By constricting the channel in curves 3 and 4 (Plate 6), the flow prisms entering the curves were rotated 90 deg, resulting in a column of water which required less superelevation to control the flow distribution. The constrictions were created by superimposing simple curves on the channel sidewalls, resulting in minimum channel widths of 14 and 13 ft, respectively, at various locations in curves 3 and 4. Concurrently several designs for the transition between curves 3 and 4 were tested. Details of the recommended transition are shown in Plate 8. Flow conditions with the recommended design transition between curves 3 and 4 are shown in Photos 3b, 4b, and 5b.

15. The original design of curve 5 consisted of an entrance and

an exit spiral with a maximum superelevation of 4.7 ft occurring at the midpoint of the curve (Plate 9). The model tests indicated that with this design, a transverse wave would occur downstream of the curve (Photo 6a). The original superelevation was approximately the same as that calculated from the coefficient developed from Equation 1. Neither developing maximum superelevation rapidly and holding it through the middle 40 percent of the curve before dropping back to a horizontal channel bed nor increasing the amount of superelevation was effective in eliminating the undesirable flow condition in curve 5. A constriction of the channel similar to that recommended for curves 3 and 4 proved to be the most practical solution to the problem (Plate 10). A flow condition with the recommended design is shown in Photo 6b.

Moanalua Road Drains

16. At Moanalua Road two box drains, one 7 by 6 ft and one 9 by 8 ft, enter the main channel as shown in Figure 3. At the design flood, the two drains will add 1500 cfs to the main channel discharge of 4800 cfs to produce a total flow of 6300 cfs downstream of the drains. The model tests indicated that this side inflow will interfere with the main channel flow and create excessive energy dissipation sufficient to overtop the 20-ft-high walls (simulated in the model) as shown in Photo 7a. Elliptical inserts (Plate 11) were placed in the drains to increase the velocity and guide the existing flow into the main channel discharge. The inserts were effective in directing the incoming flow and permitted the flow from the drains to enter and combine with the main channel flow without overtopping the sidewalls (Photo 7b). This reduced energy dissipation and improved flow characteristics.

Relief Drain and Diversion Channel

17. At the downstream end of the project, flow is to be divided between a relief drain consisting of a horseshoe conduit approximately 11 ft in diameter and a rectangular diversion channel which increases in

width from 8.5 to 17 ft through a severe curve (Plate 12). One of the design objectives is to divide the design discharge so that approximately 60 percent of the total flow will be diverted to the relief drain and 40 percent will enter the existing downstream channel.

18. The original design called for a slight horizontal curve at the entrance to the county relief drain, but the alignment was later altered by the sponsoring agency, eliminating this curve. A flow condition with the original design is shown in Photo 8a. Approximately 4050 cfs was diverted into the relief drain, and 2250 cfs entered the diversion channel. Based on the results of the model investigation, the only modification recommended for the relief drain with the straighter alignment was to provide a curved roof in order to improve hydraulic efficiency and entrance flow conditions. A flow condition with the recommended design is shown in Photo 8b.

19. Since the diversion channel turns through 80 deg with a short-radius curve, attempting to control flow distribution with superelevation alone required steeper slopes than were practical to construct. A flow condition with the original design is shown in Photo 9a. A slight constriction of the channel, combined with superelevation, which proved effective in distributing flows in previous curves, did not appreciably improve flow in the diversion channel. A design consisting of a severe constriction to 3.5 ft with no superelevation (Plate 13) resulted in the most satisfactory flow distribution exiting the curve (Photo 9b). However, this curve extended beyond the project limits, and the constriction was sufficiently narrow to cause construction difficulties and possibly trap trash and debris. The final design that was proposed by the sponsoring agency is shown in Plate 14. This design constricts the channel width from 8.5 to 8.0 ft, and no superelevation is provided. This does not provide good flow distribution, but the conditions are within permissible limits (Photo 9c). The model indicated a division of flow for the final design of 3900 cfs (62 percent) into the relief drain and 2400 cfs (38 percent) into the diversion channel. This compares with a distribution of 4050 and 2250 cfs obtained with the original design.

PART IV: DISCUSSION

20. Even though all of the convergence in the upstream transition is provided on the right side of the channel, a 1 to 16 transition is sufficient for good hydraulic flow conditions.

21. The model study indicated that supercritical flow characteristics are sensitive to both the alignment of a curve and the amount of superelevation provided in various portions of a curve, particularly in a curve formed of spirals. It is easier to provide free drainage when the channel invert is superelevated about the inside of the curve rather than about the center line. This also provides less disturbance of flow and is somewhat similar to the greater comfort and stability provided by highways superelevated about the insides of the curves. Further, more generalized testing of supercritical channels may demonstrate the feasibility of improving flow distribution by using vertical curves similar to those used in highway design between changes in grades.

22. Curves 3-5 and the diversion channel indicated that superelevation in itself is not always a practical solution to the problem of flow distribution along curves. Constrictions, either alone or in addition to superelevation, may prove to be a more feasible design. A constriction in channel widths that rotates the entering flow prism 90 deg requires less superelevation and improves flow distribution throughout the curve. Although guide vanes were not examined in this model due to the limited width of the channel, they could prove to be a viable alternative with and without superelevation and constrictions.

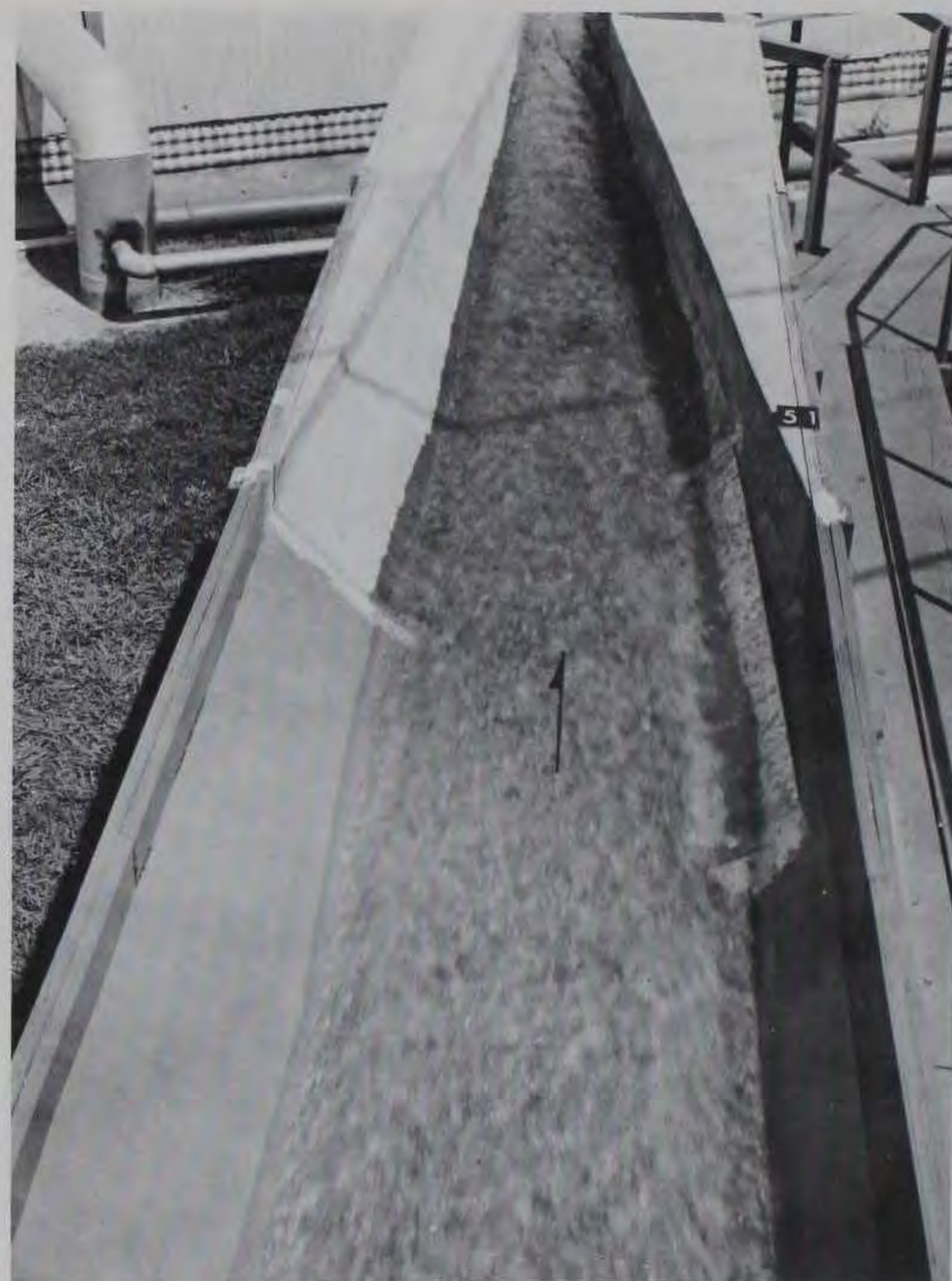
23. Testing of the simulated Moanalua Road drains indicated that accelerating and guiding the entering flow will provide the reduced energy dissipation necessary for satisfactory confluence of the side drainage into the main channel.

24. The degree of curvature within the diversion channel is so great that no ideal solution could be obtained, and the solution was a matter of achieving acceptable flow conditions.

25. Water-surface profiles and velocities obtained with the Waimano Project original and recommended designs installed in the model are presented in Appendix A.



a. Original design



b. Recommended design

Photo 1. Flow conditions with original and recommended design transitions, discharge 4800 cfs



a. Original design

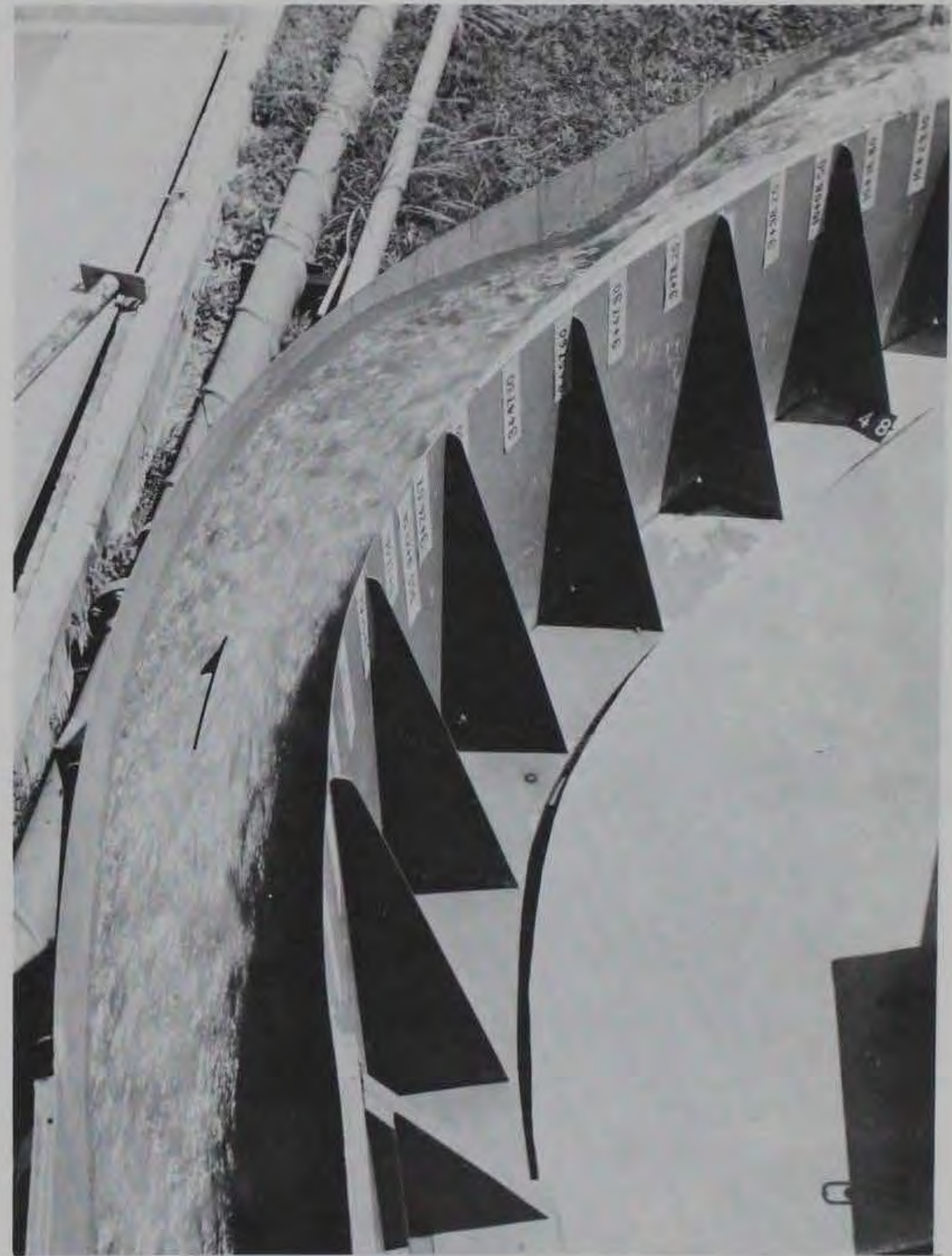


b. Recommended design

Photo 2. Flow conditions with original and recommended designs for curve 1, discharge 4800 cfs

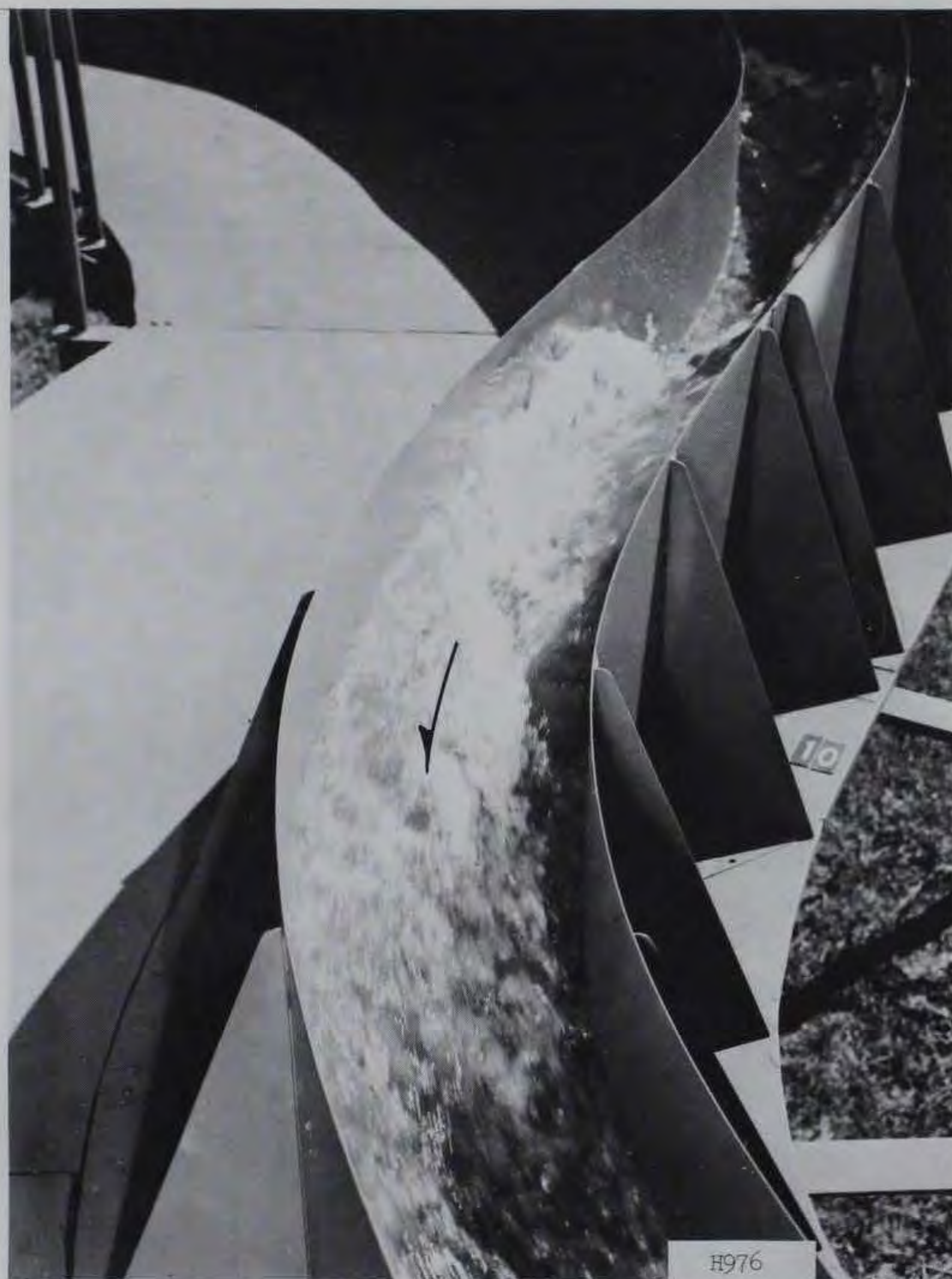


a. Original design



b. Recommended design

Photo 3. Flow conditions with original and recommended designs for curve 3, discharge 4800 cfs



a. Original design



b. Recommended design

Photo 4. Flow conditions with original and recommended designs for transitions from curve 3 to curve 4, discharge 4800 cfs



a. Original design



b. Recommended design

Photo 5. Flow conditions for original and recommended designs for curve 4, discharge 4800 cfs



a. Original design



b. Recommended design

Photo 6. Flow conditions for original and recommended designs for curve 5, discharge 4800 cfs



a. Original design



b. Recommended design

Photo 7. Flow conditions with original and recommended designs for Moanalua Road drains, discharges 4800 cfs (main channel) and 1500 cfs (drains)



a. Original design, discharge 4050 cfs



b. Recommended design, discharge 3900 cfs

Photo 8. Flow conditions with original and recommended designs for relief drain



a. Original design for diversion channel,
discharge 2250 cfs



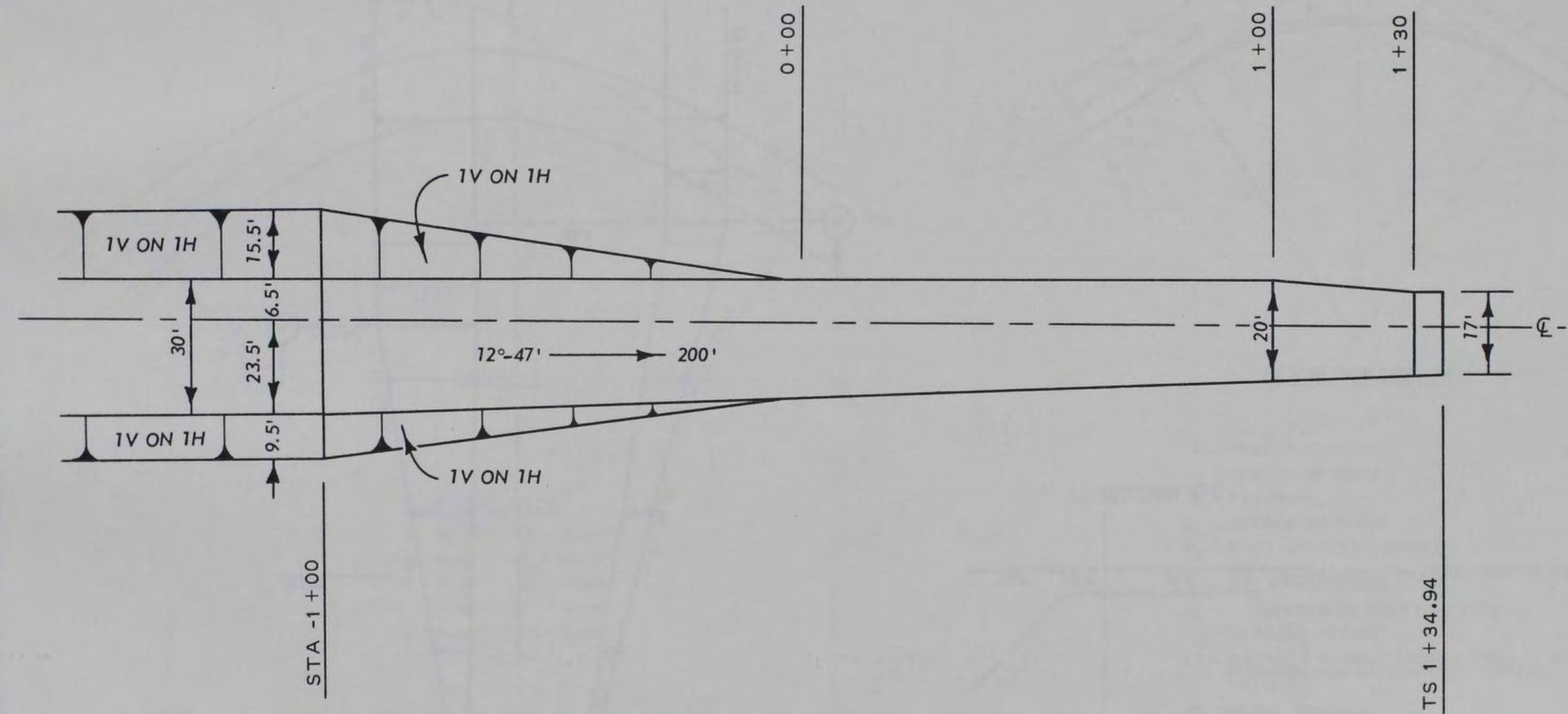
b. Diversion channel design with severe con-
striction and no superelevation, discharge
2400 cfs

Photo 9. Flow conditions with diversion channel designs (sheet 1 of 2)

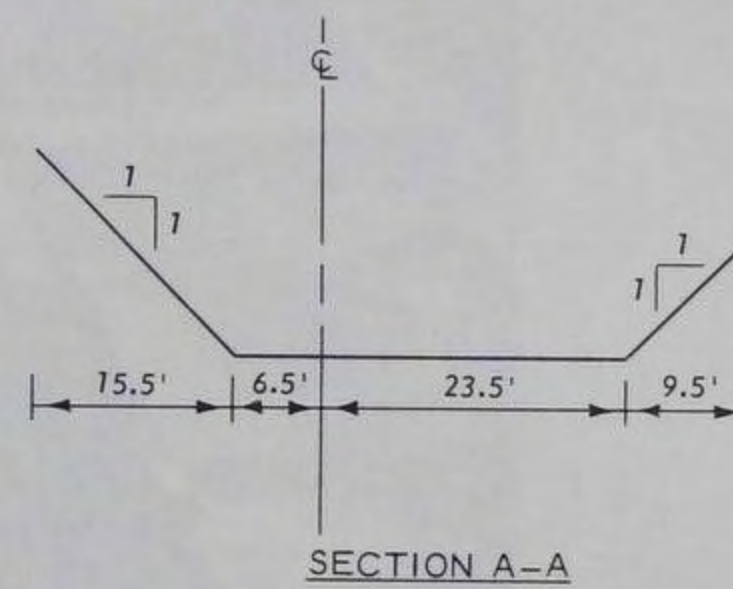
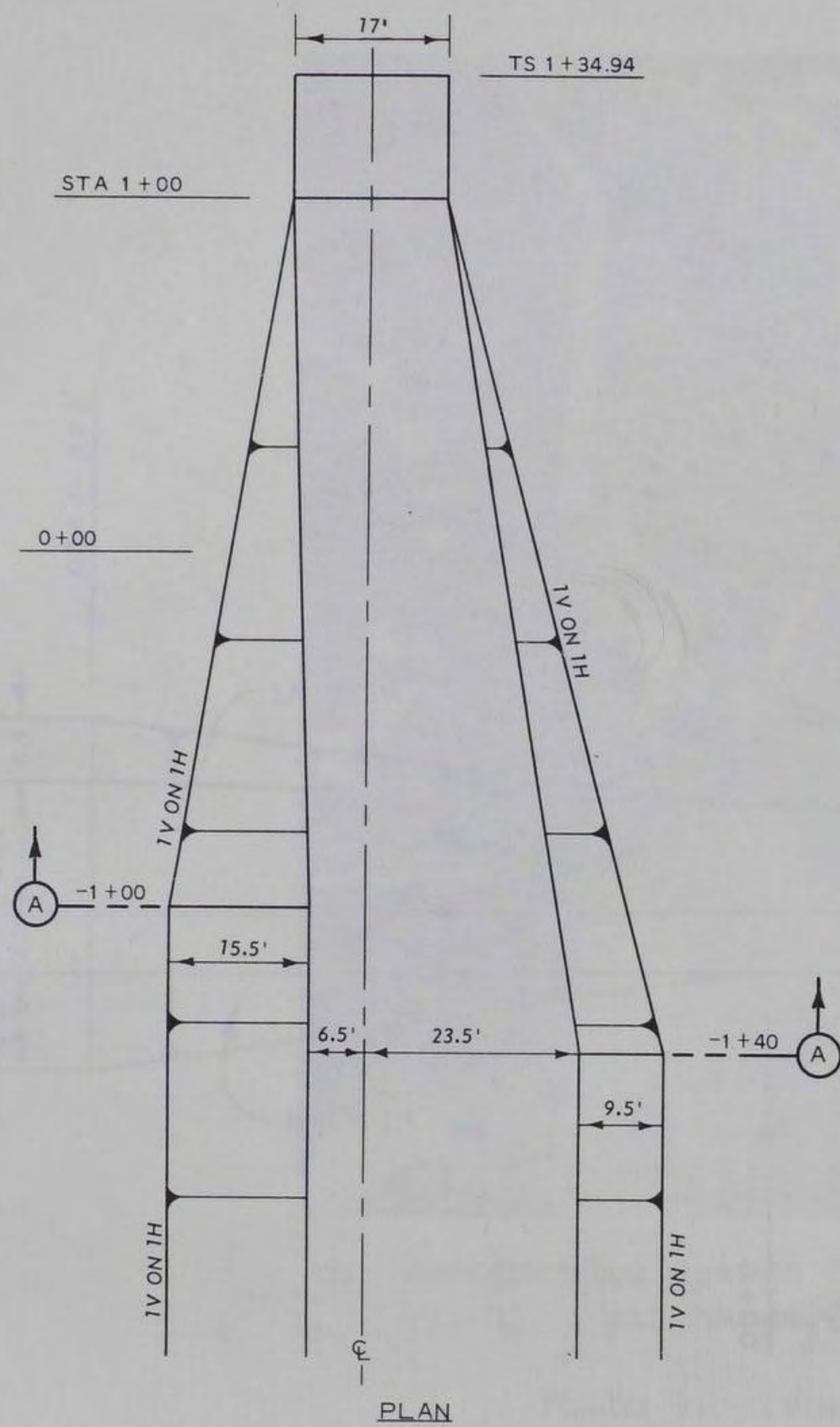


c. Recommended design for diversion channel,
discharge 2400 cfs

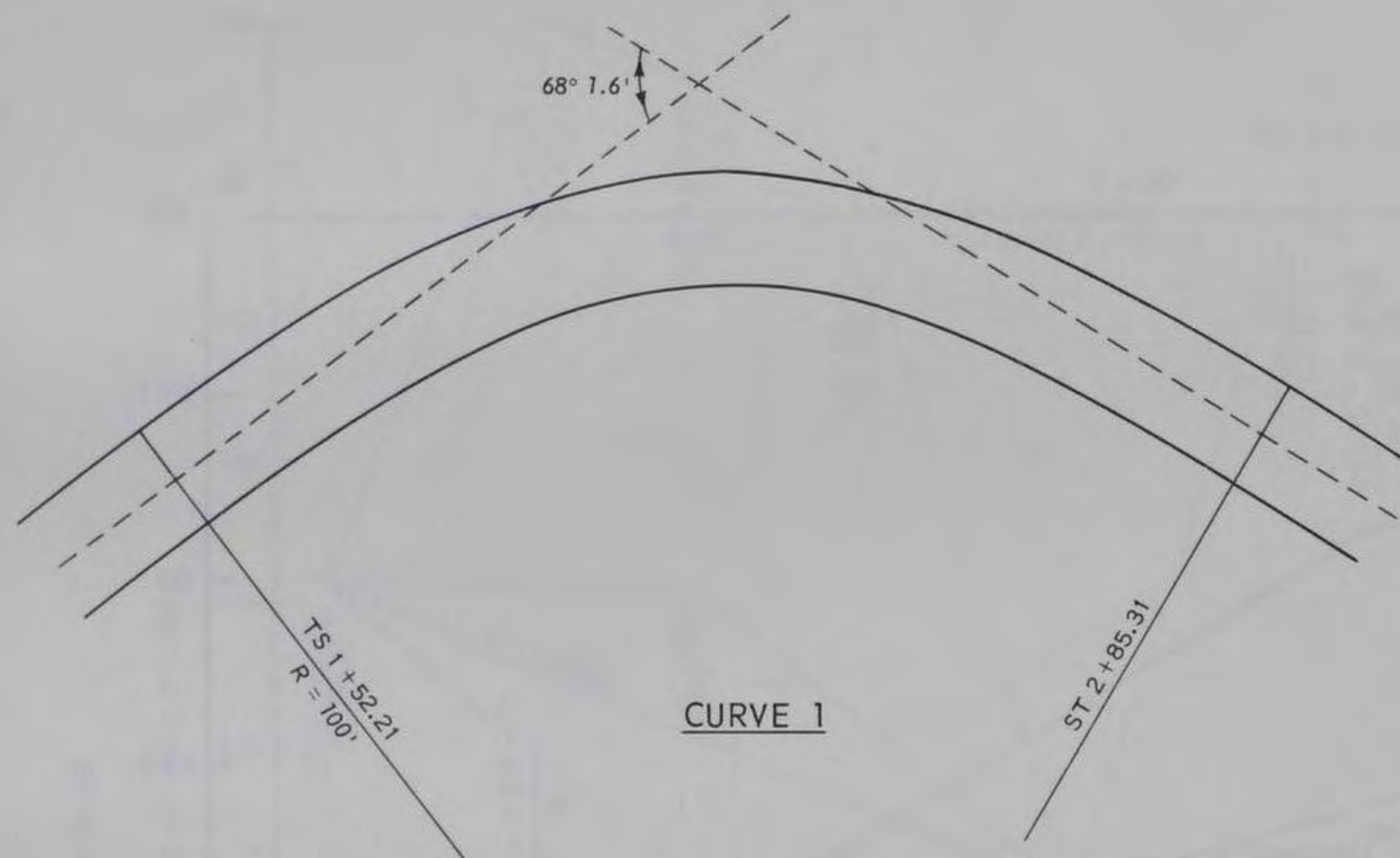
Photo 9. (sheet 2 of 2)



ORIGINAL ENTRANCE TRANSITION

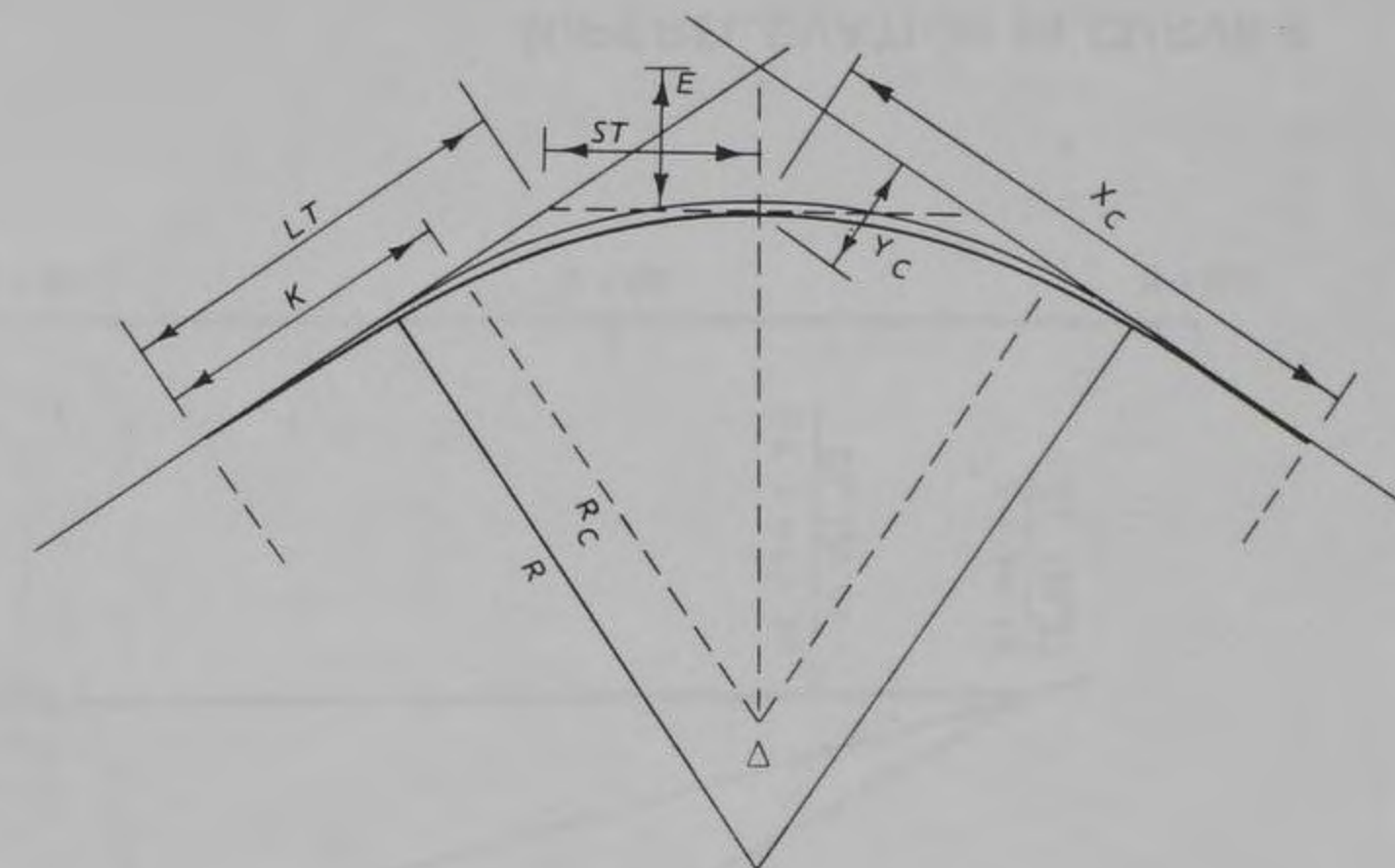


RECOMMENDED ENTRANCE TRANSITION



SPIRAL DATA

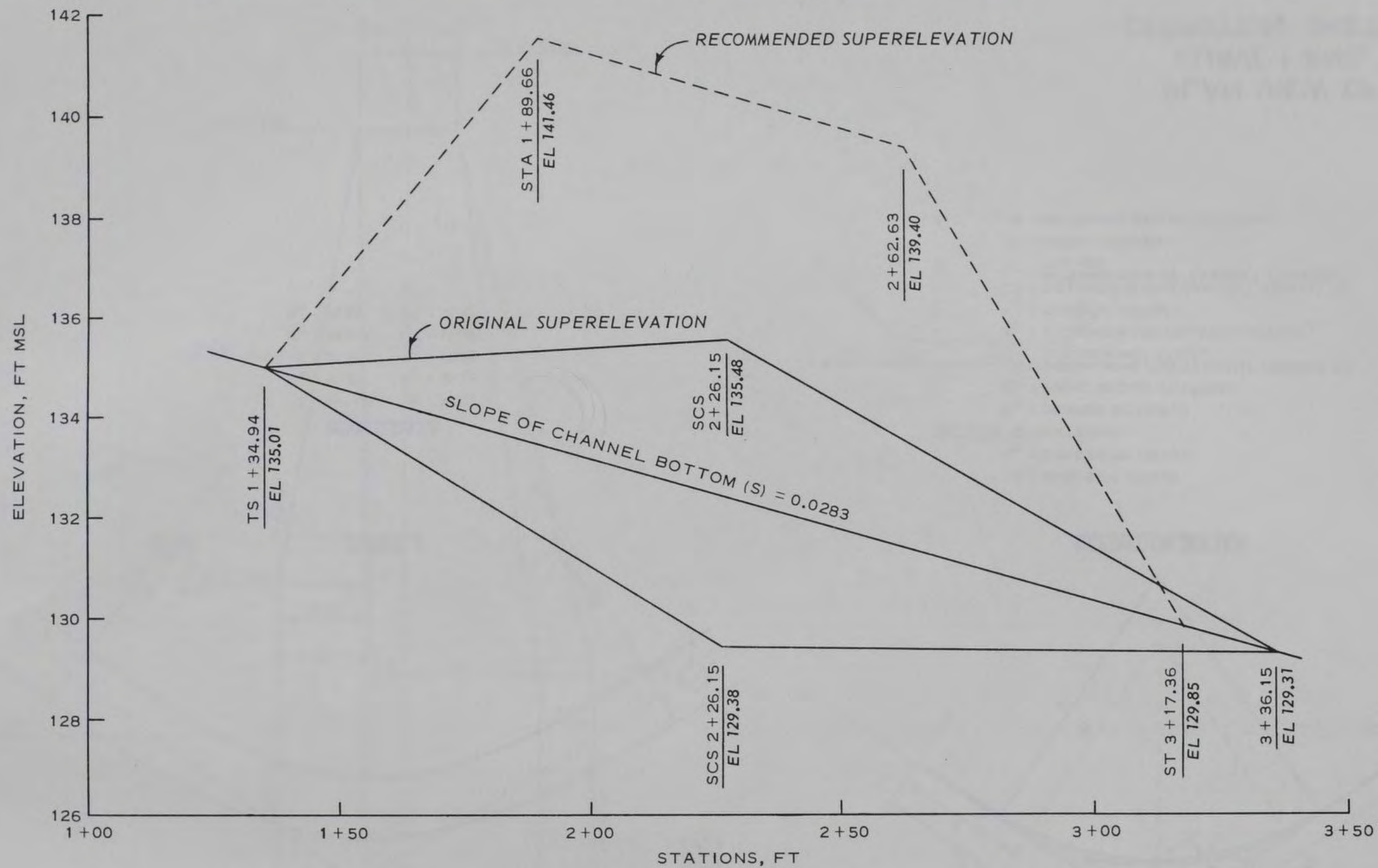
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$E = 21.33'$	$Y_C = 17.66'$
$D_C = 74.84^\circ$	$LT = 61.99'$
$R_C = 76.55'$	$ST = 31.47'$



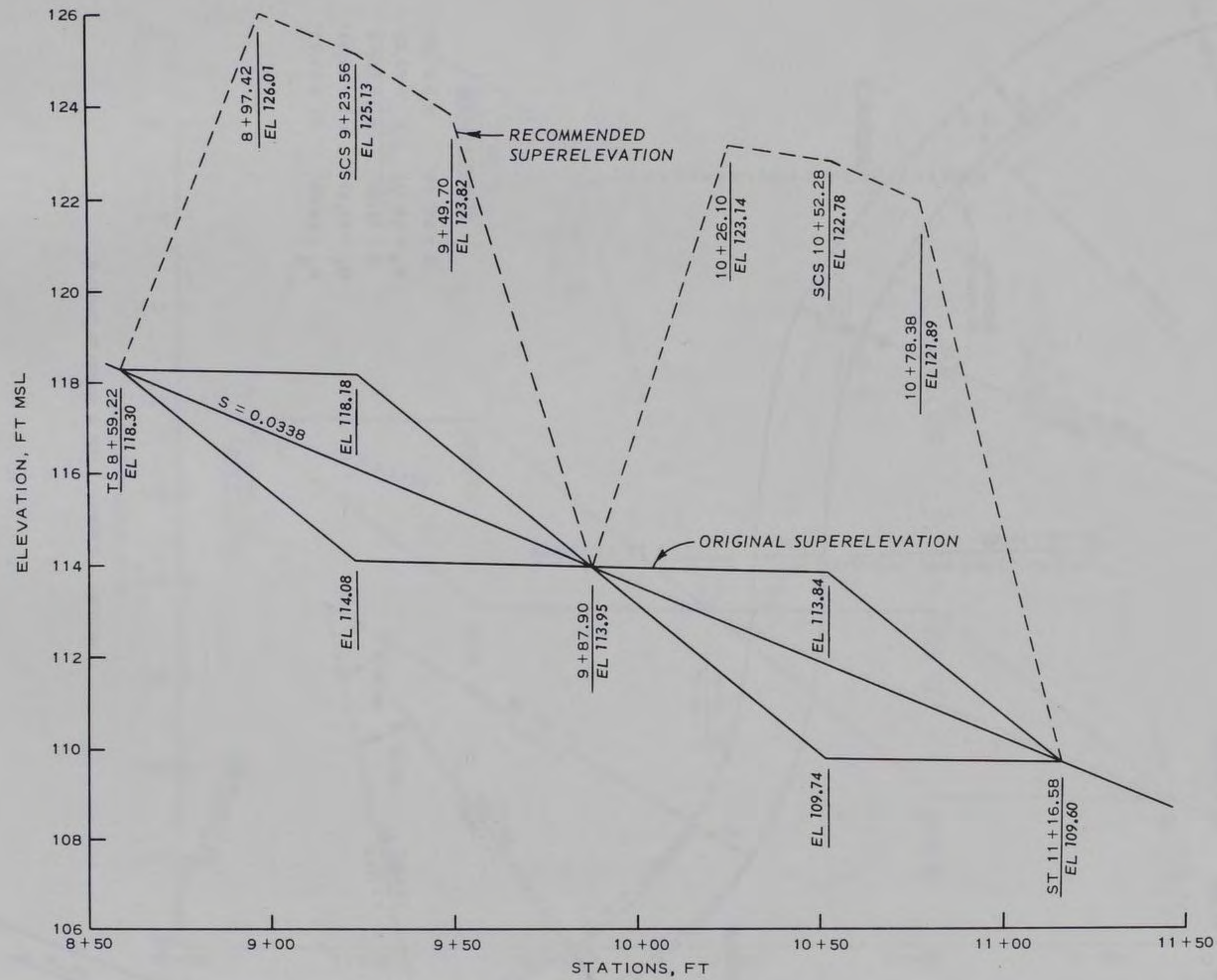
DEFINITION SKETCH

- Δ = ANGLE OF CURVE
- L_s = LENGTH OF SPIRAL
- E = EXTERNAL
- D_C = DEGREE OF CURVE
- R_C = FINAL RADIUS OF SPIRAL
- K = DISTANCE ALONG TANGENT FROM ST TO END OF FIRST SPIRAL
- X_C = X COORDINATE RELATING WITH Y_C
- Y_C = TANGENT OFFSET
- LT = DISTANCE ALONG TANGENT FROM ST TO INTERSECTION OF TANGENT THROUGH THE SCS
- ST = SPIRAL TANGENT
- R = BEGINNING RADIUS OF SPIRAL

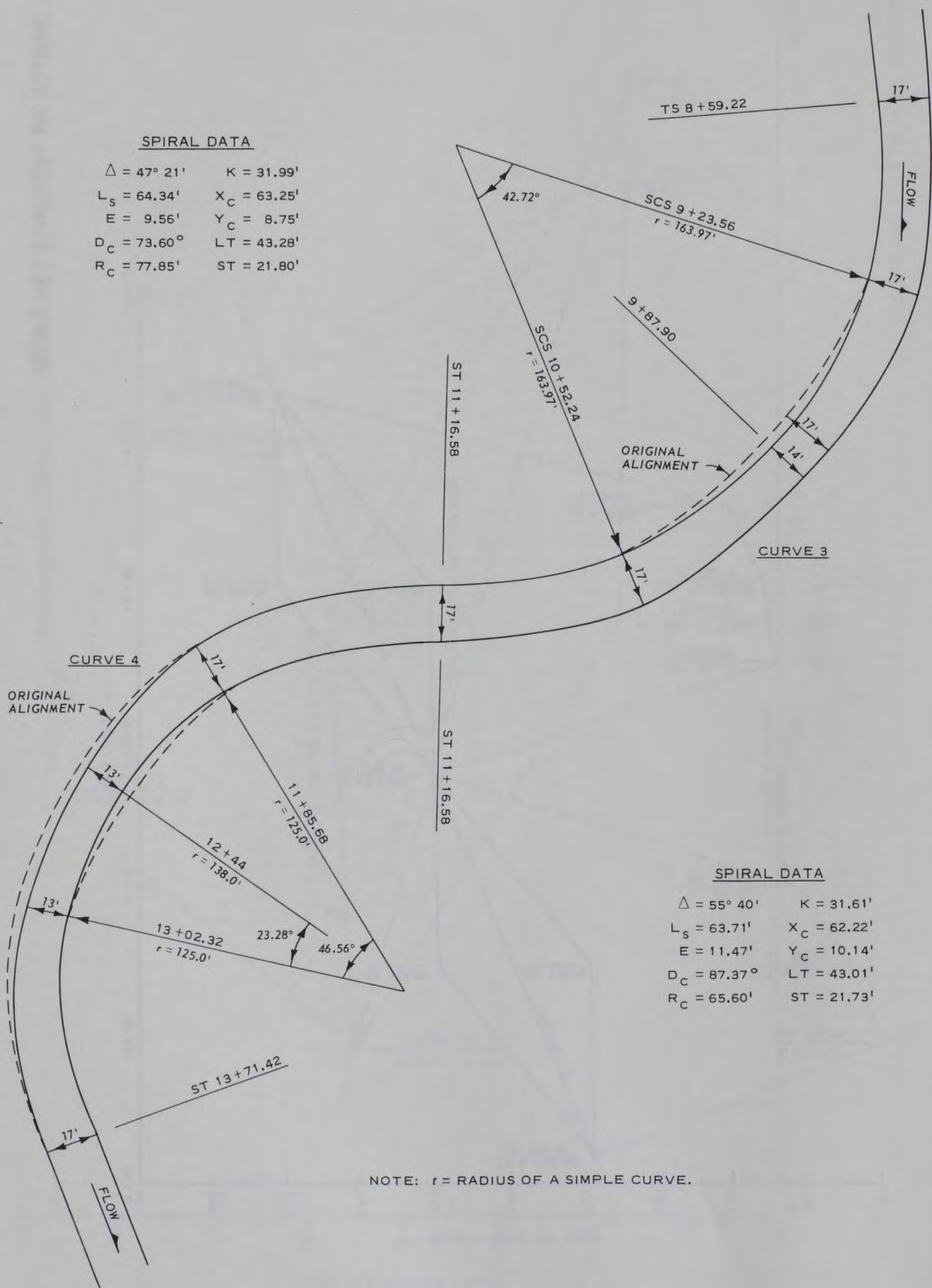
PLAN VIEW OF CURVE 1 AND DEFINITION SKETCH



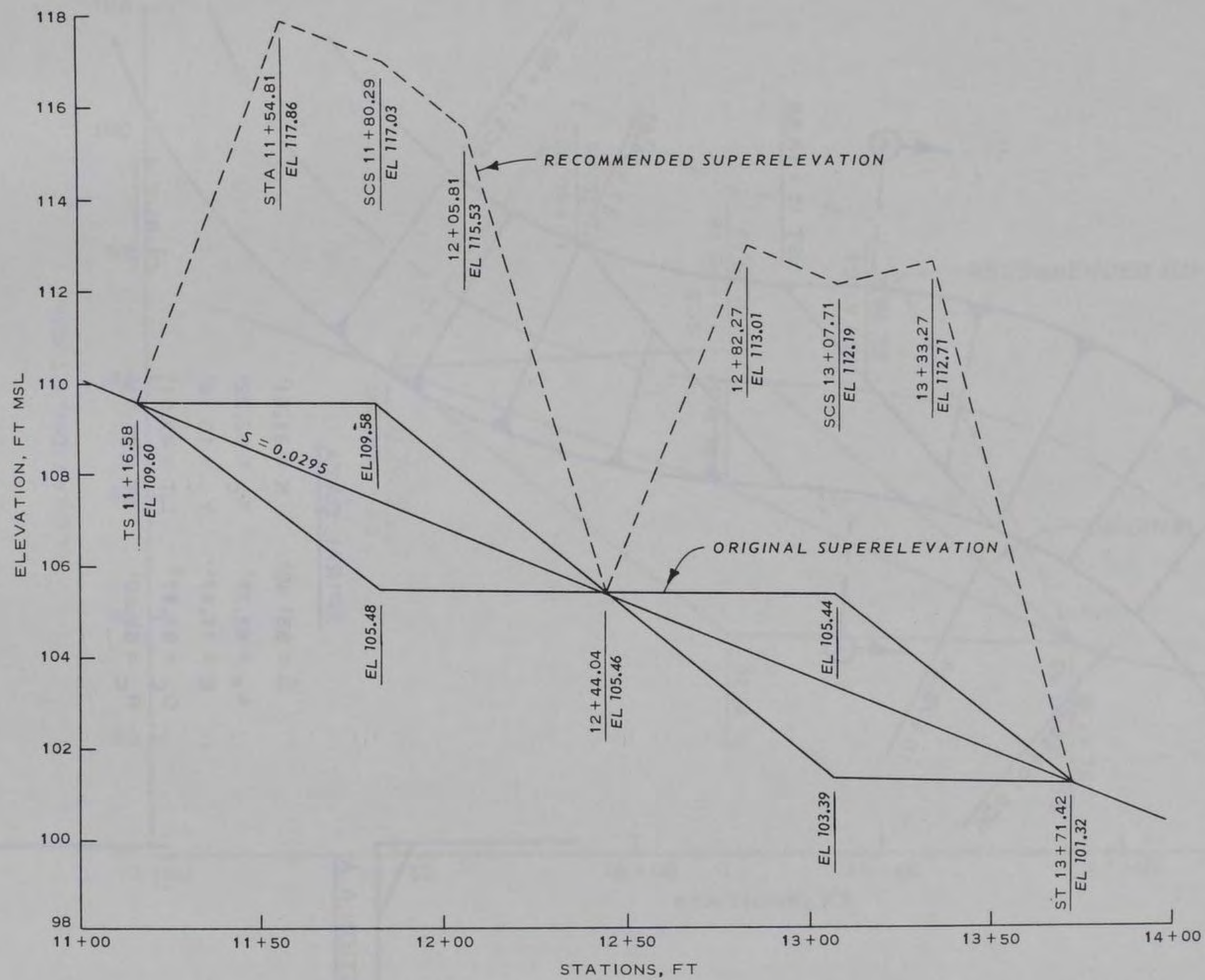
SUPERELEVATION IN CURVE 1



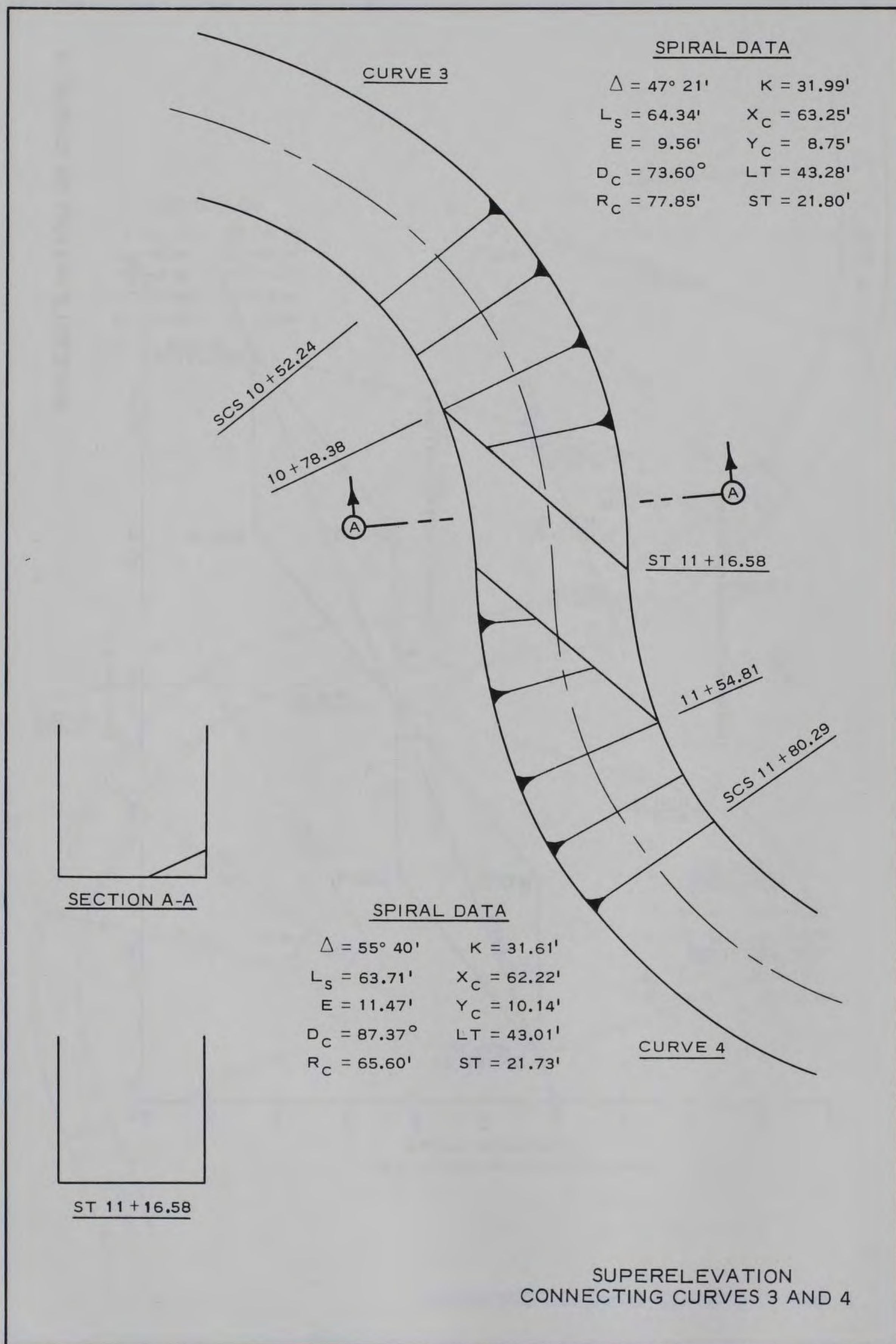
SUPERELEVATION IN CURVE 3

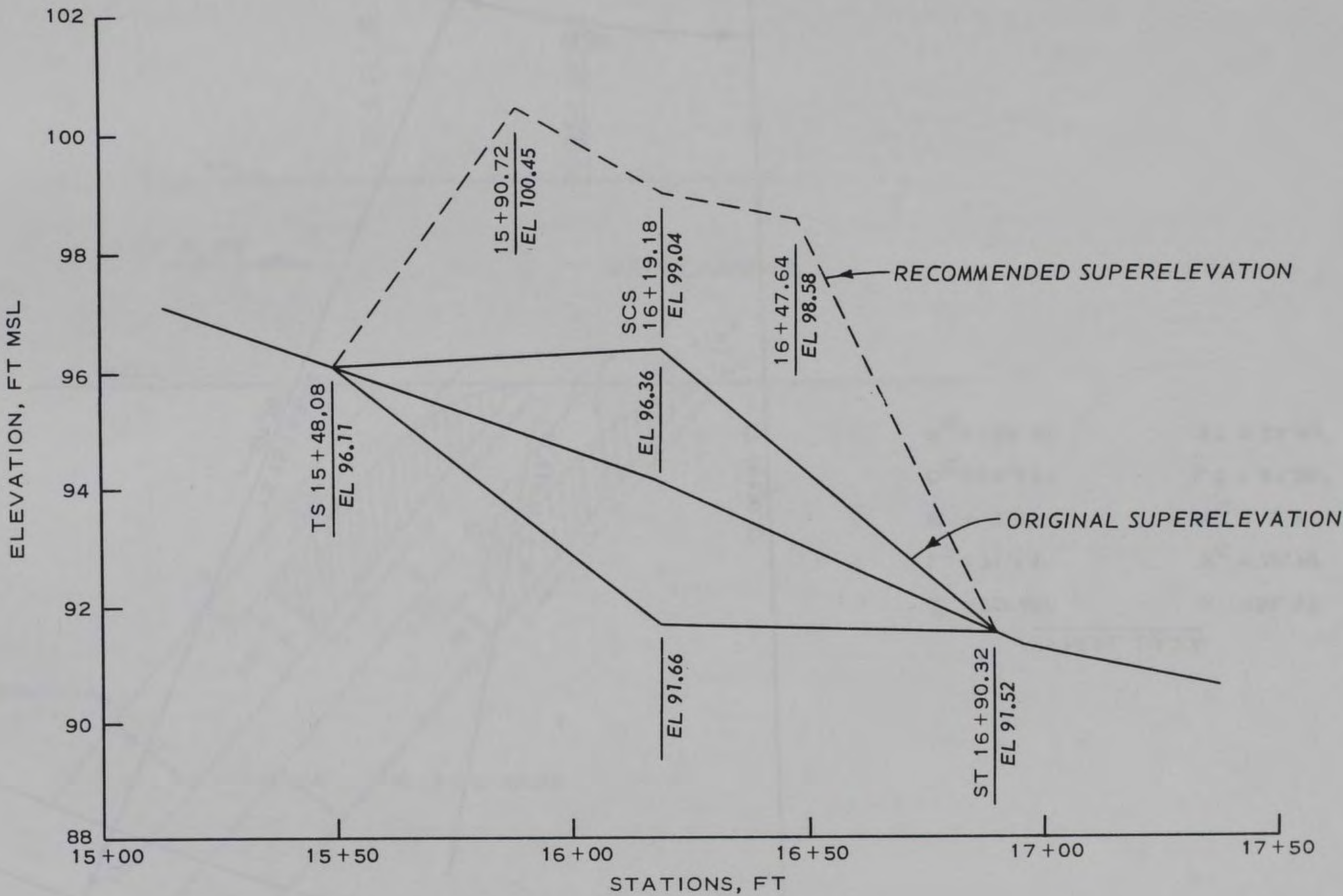


CONSTRICTIONS IN CURVES 3 AND 4

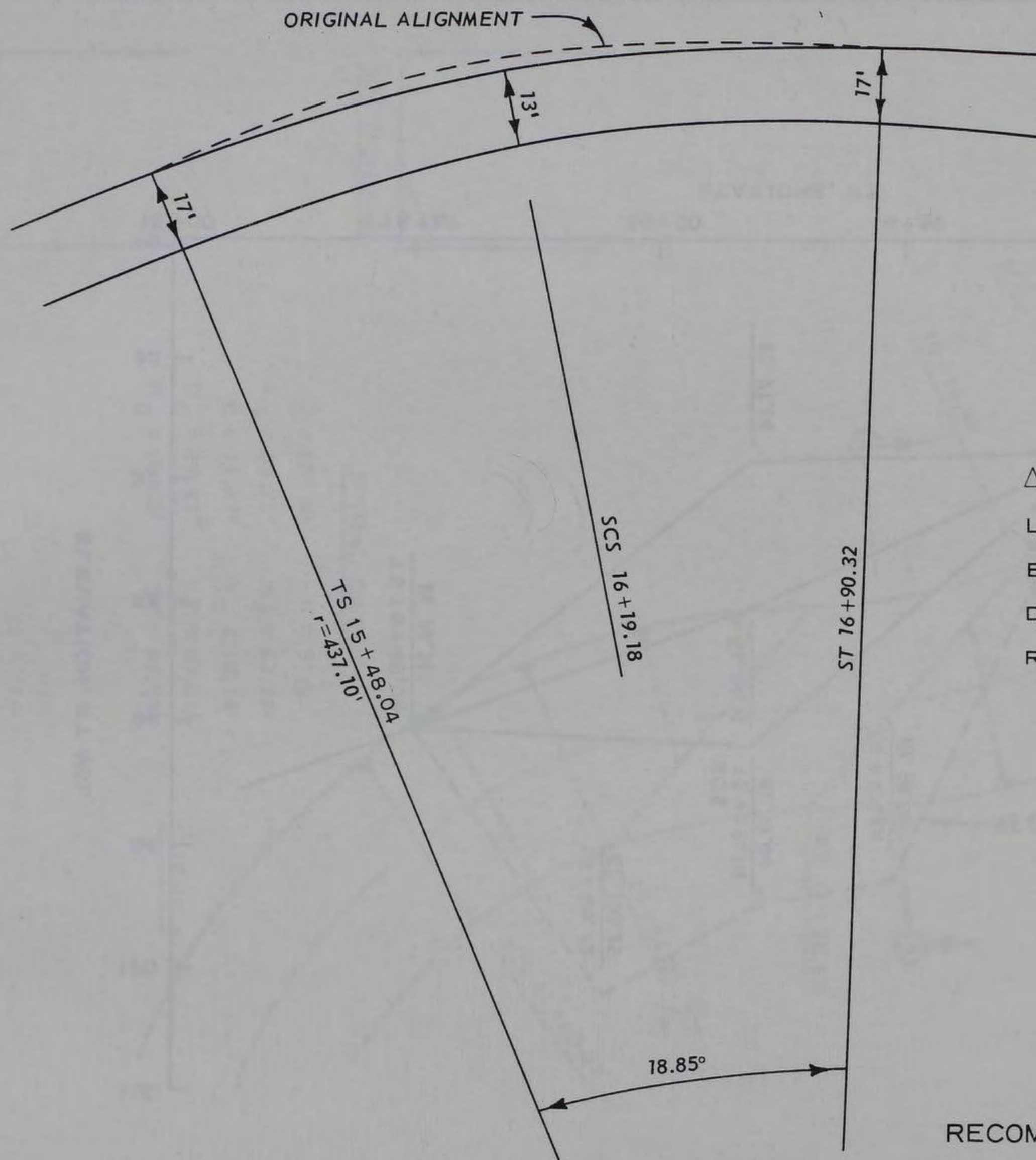


SUPERELEVATION IN CURVE 4





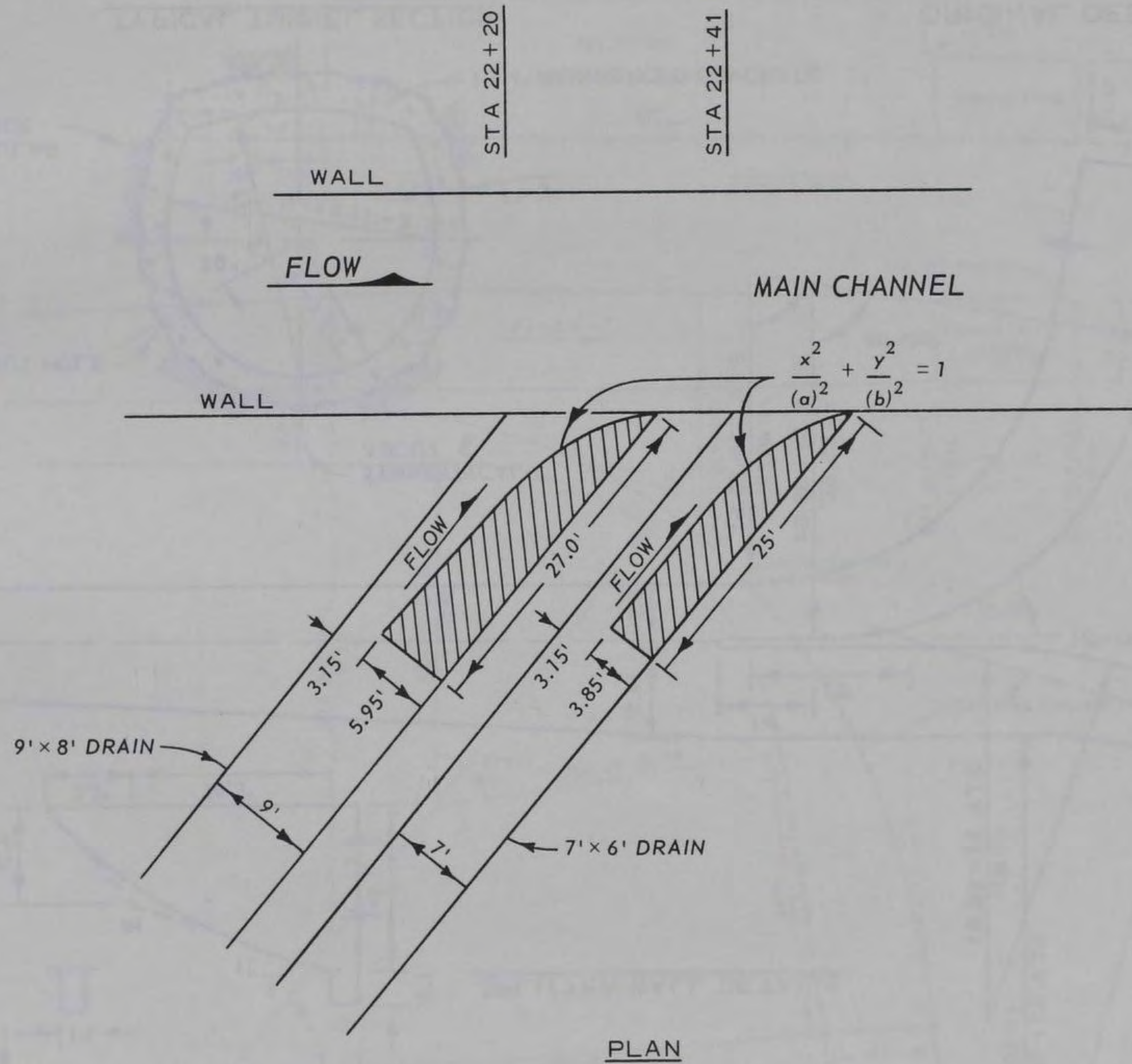
SUPERELEVATION IN CURVE 5



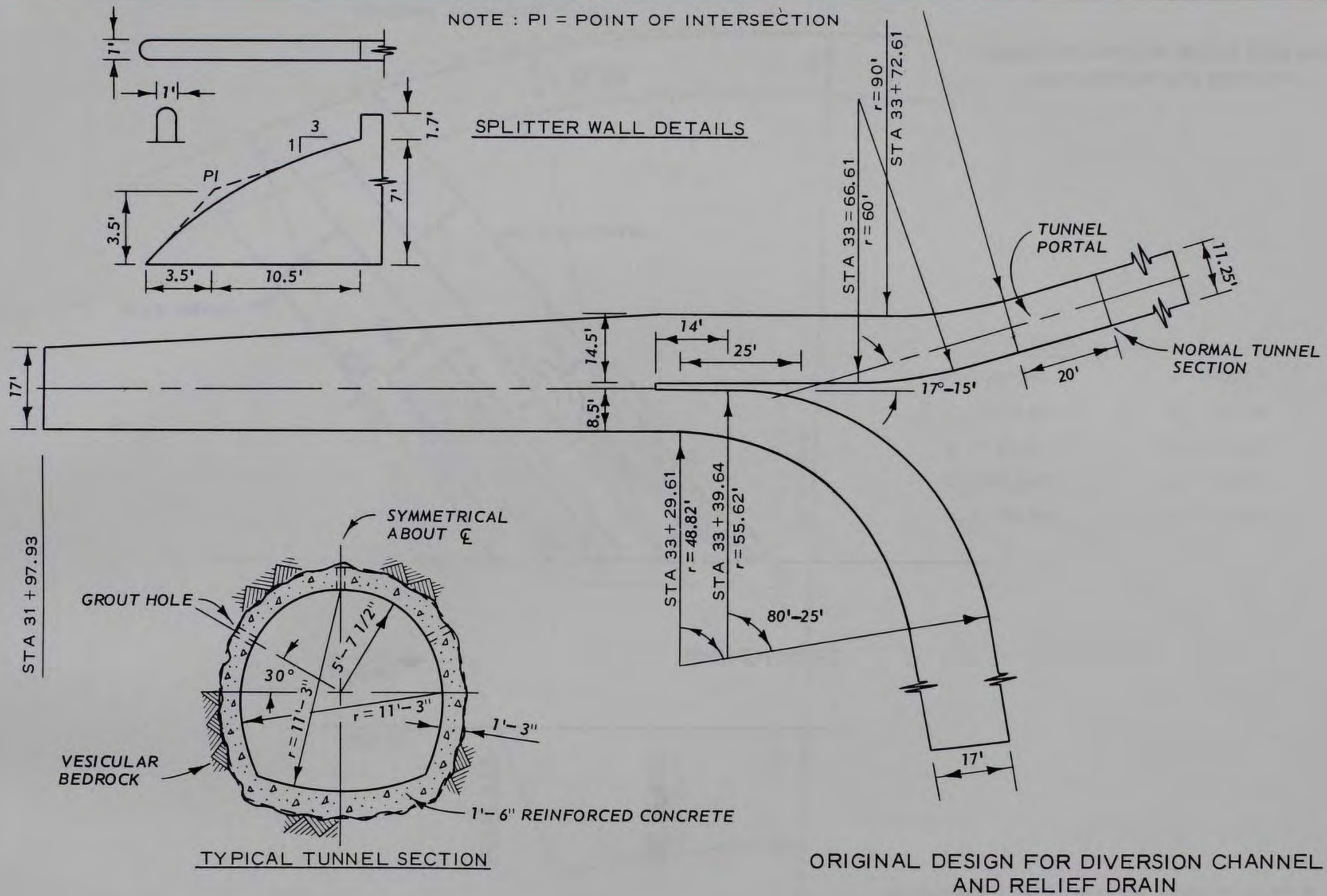
SPIRAL DATA

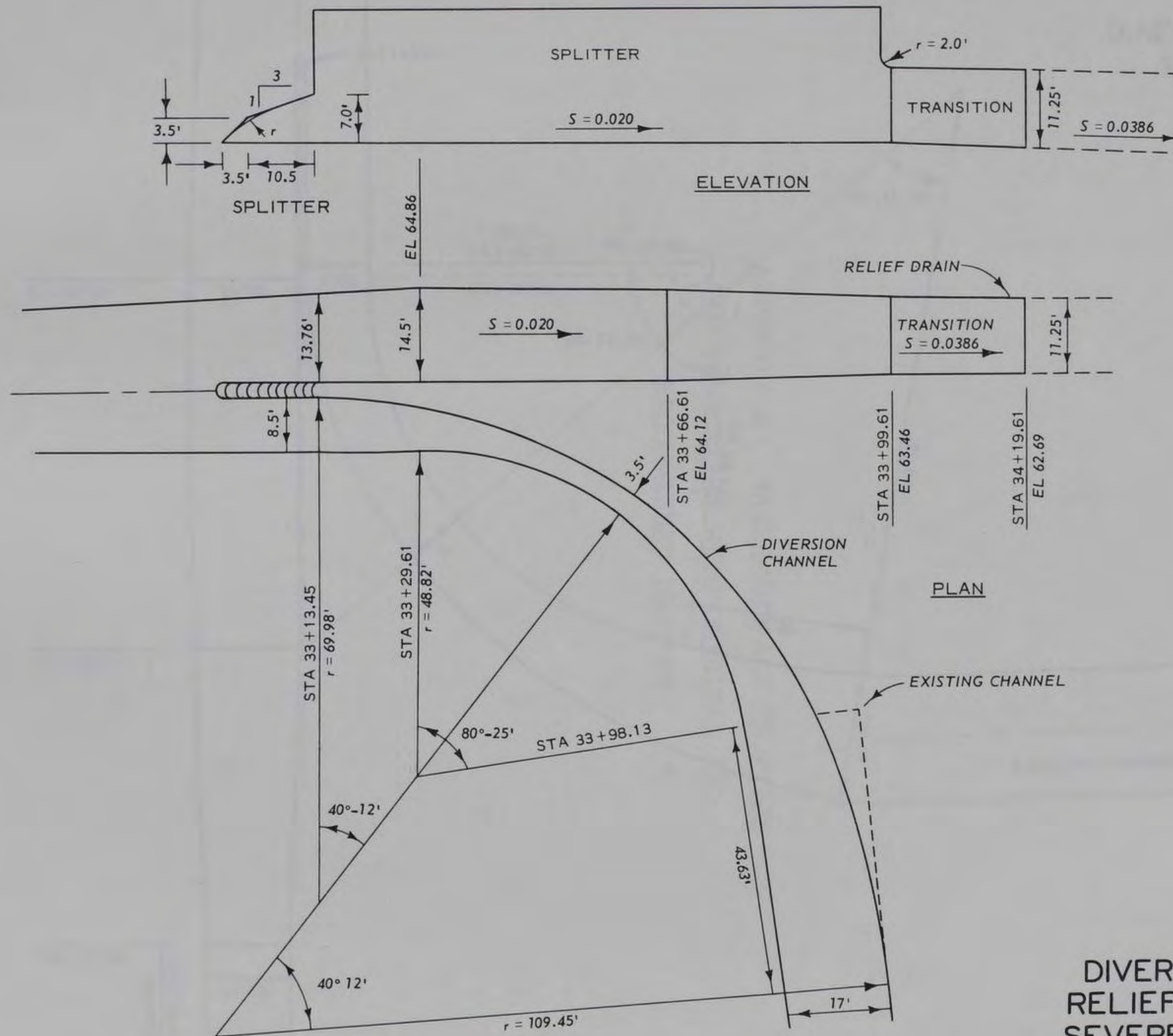
$\Delta = 25^\circ 46'$	$K = 35.51'$
$L_S = 71.14'$	$X_C = 70.78'$
$E = 5.45'$	$Y_C = 5.31'$
$D_C = 36.22^\circ$	$LT = 47.56'$
$R_C = 158.20'$	$ST = 23.83'$

RECOMMENDED DESIGN FOR CURVE 5

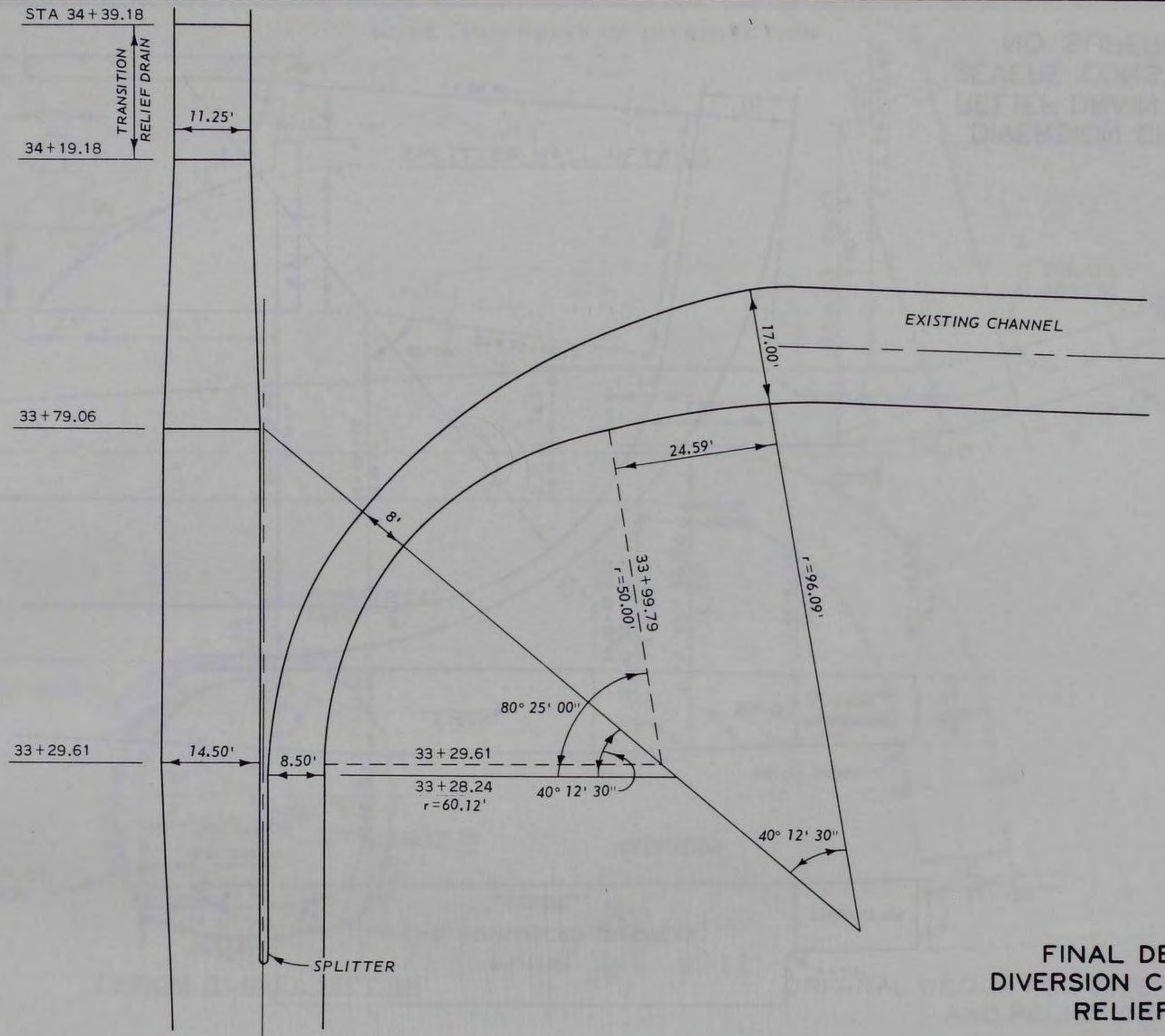


RECOMMENDED DESIGN
FOR MOANALUA ROAD DRAINS



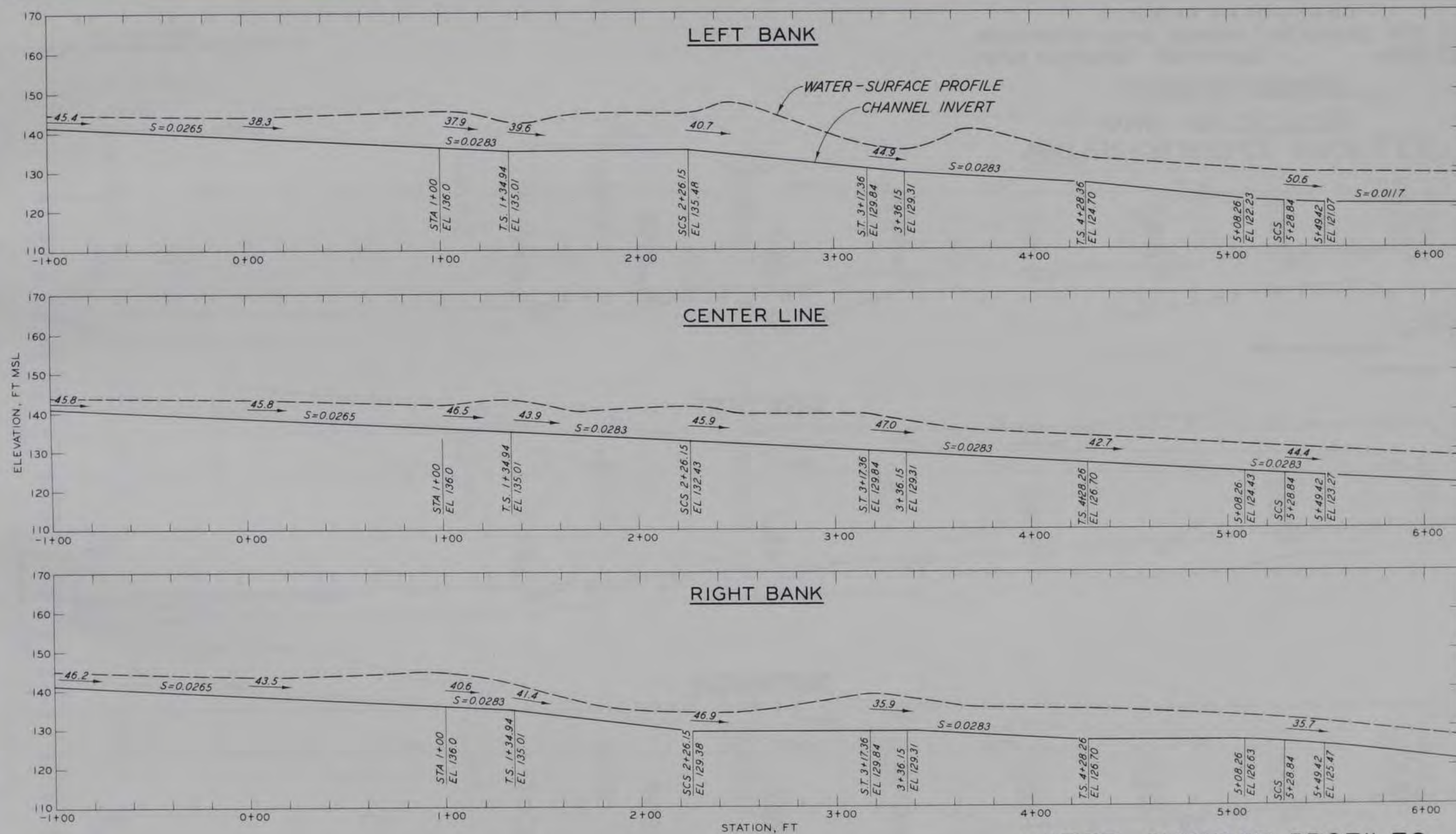


DIVERSION CHANNEL AND
RELIEF DRAIN DESIGN WITH
SEVERE CONSTRICTION AND
NO SUPERELEVATION



FINAL DESIGN FOR
DIVERSION CHANNEL AND
RELIEF DRAIN

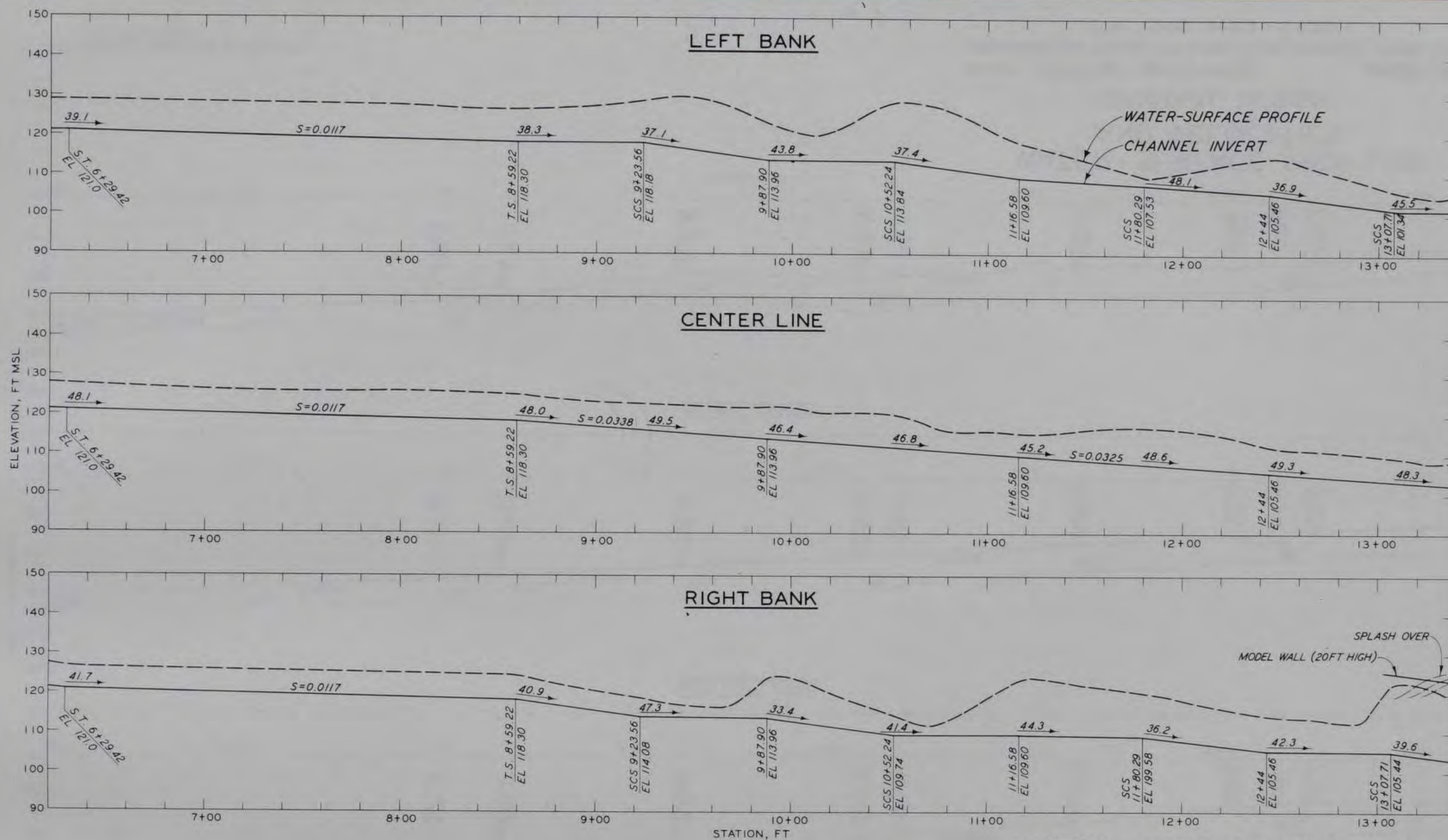
APPENDIX A : WATER-SURFACE PROFILES
AND VELOCITIES WITH ORIGINAL AND
RECOMMENDED DESIGNS

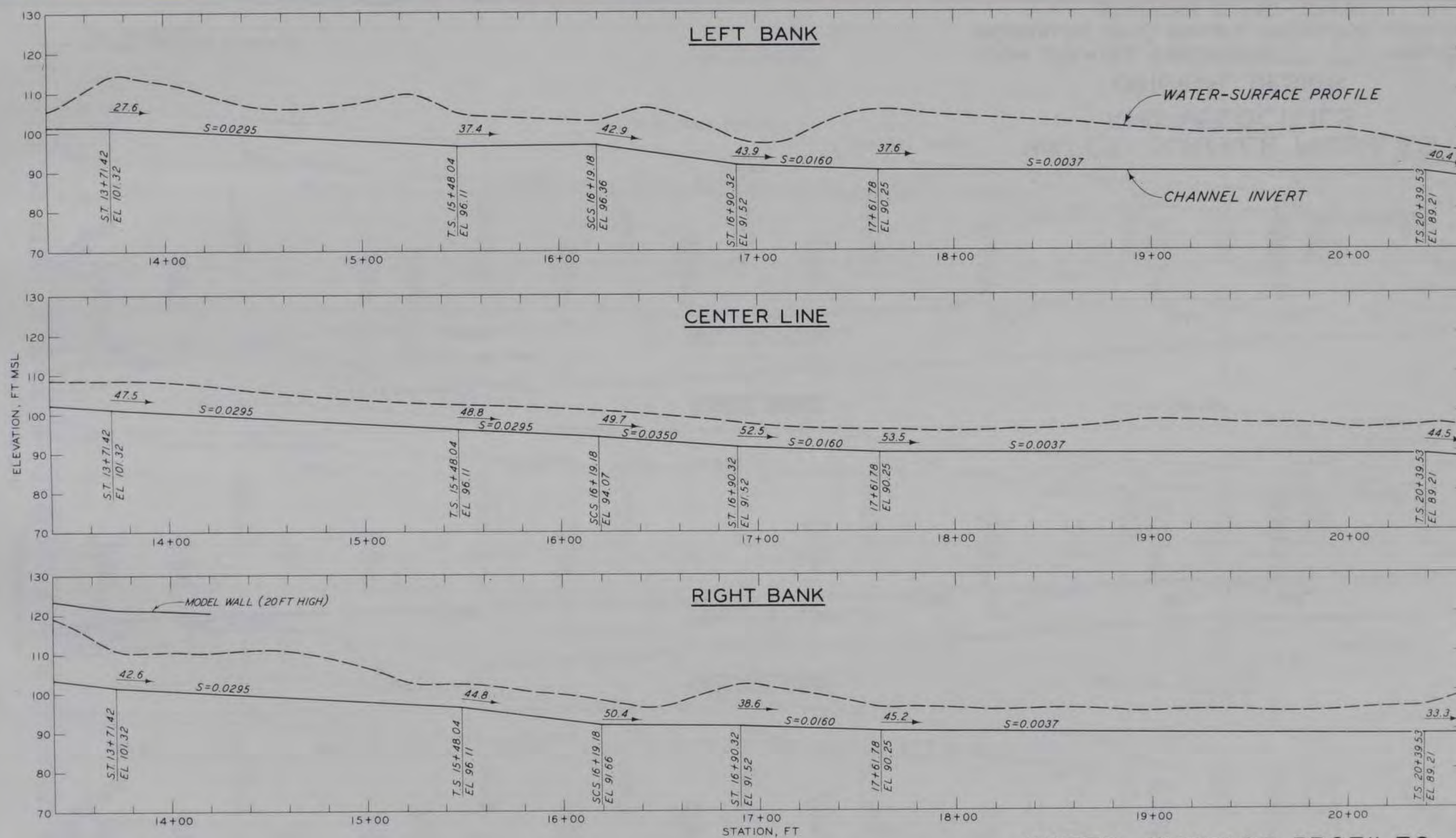


WATER - SURFACE PROFILES AND VELOCITIES ORIGINAL DESIGN

MAIN CHANNEL DISCHARGE 4800 CFS
MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
STATIONS -1+00 - 6+20

31.1 → DENOTES VELOCITIES IN PROTOTYPE
FEET PER SECOND

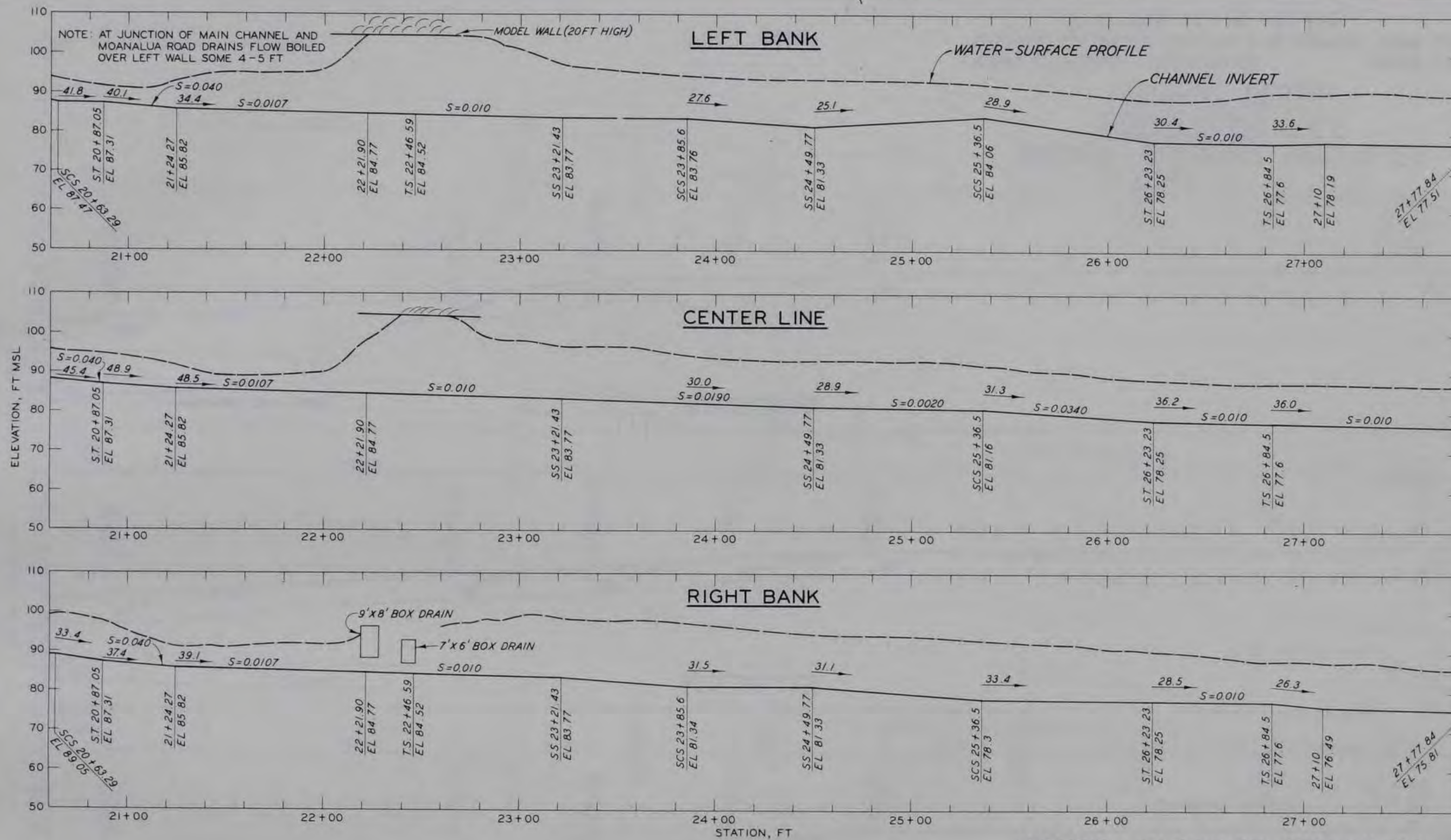




WATER-SURFACE PROFILES AND VELOCITIES ORIGINAL DESIGN

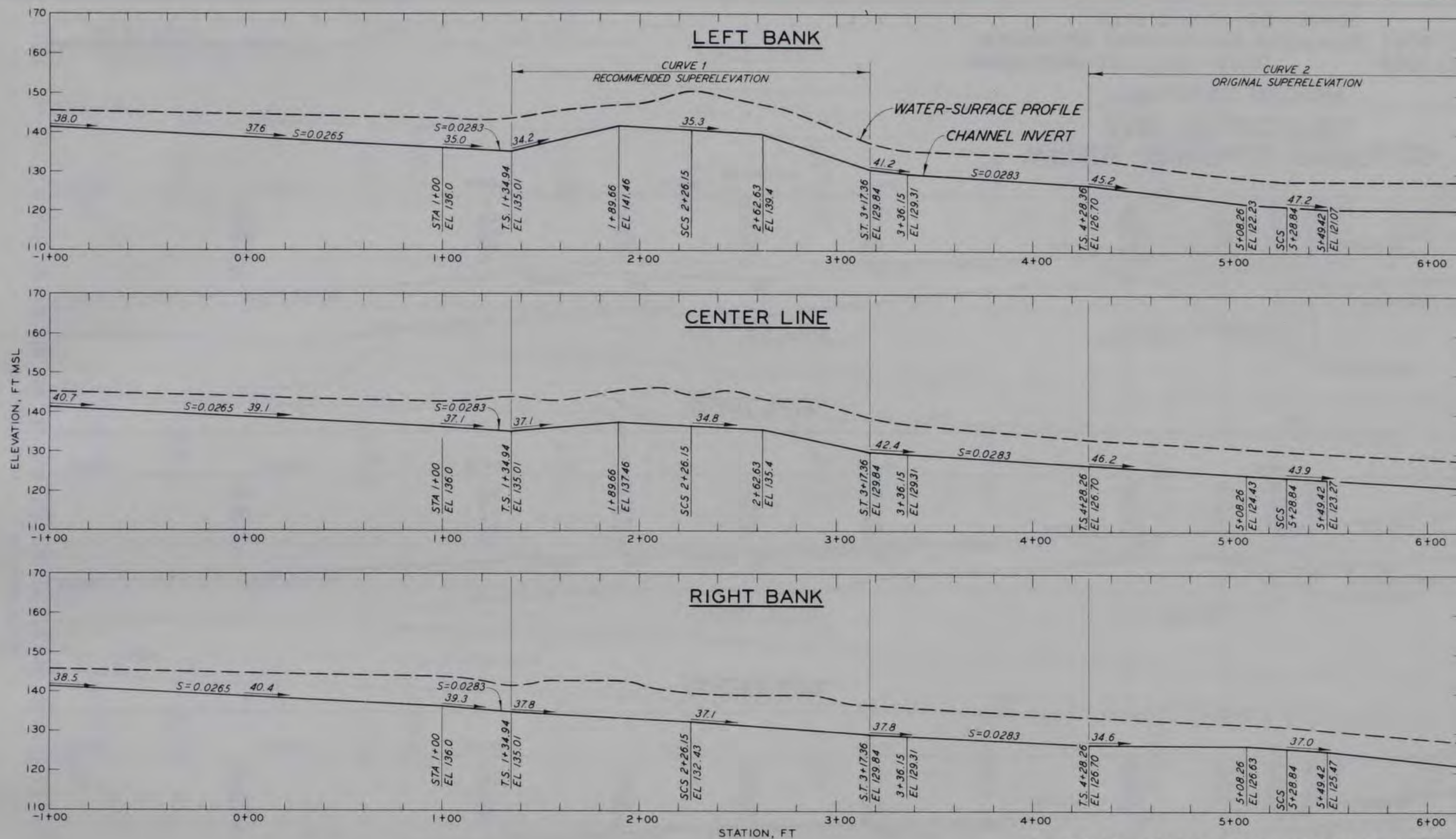
MAIN CHANNEL DISCHARGE 4800 CFS
MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
STATIONS 13+40 - 20+60

31.1 → DENOTES VELOCITIES IN PROTOTYPE
FEET PER SECOND



WATER - SURFACE PROFILES AND VELOCITIES ORIGINAL DESIGN

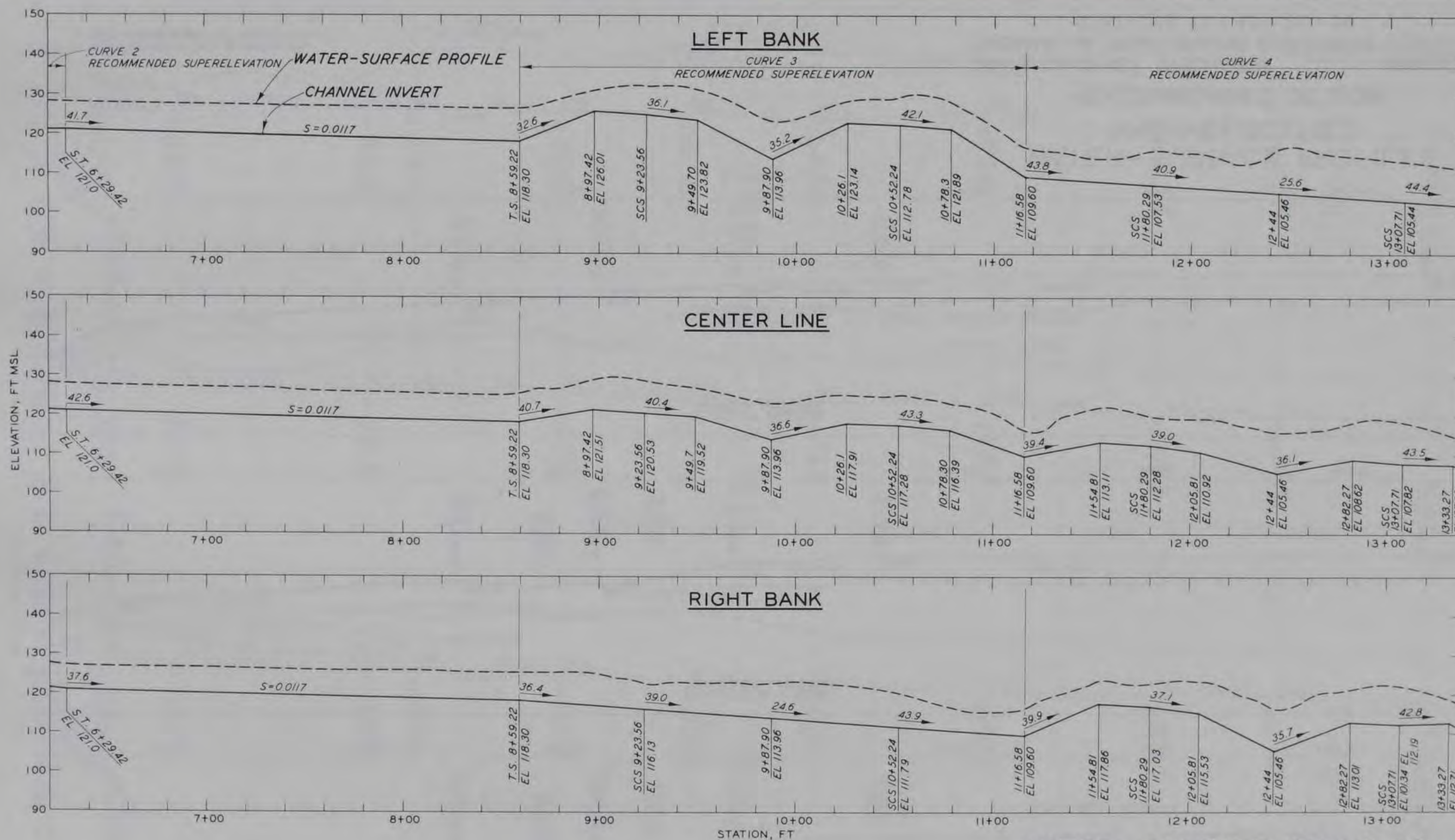
MAIN CHANNEL DISCHARGE	4800 CFS
MOANALUA ROAD DRAINS DISCHARGE	1500 CFS
STATIONS 20 + 60 - 27 + 80	



WATER-SURFACE PROFILES AND VELOCITIES RECOMMENDED DESIGN

MAIN CHANNEL DISCHARGE 4800 CFS
MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
STATIONS -1+00 - 6+20

31.1
DENOTES VELOCITIES IN PROTOTYPE
FEET PER SECOND

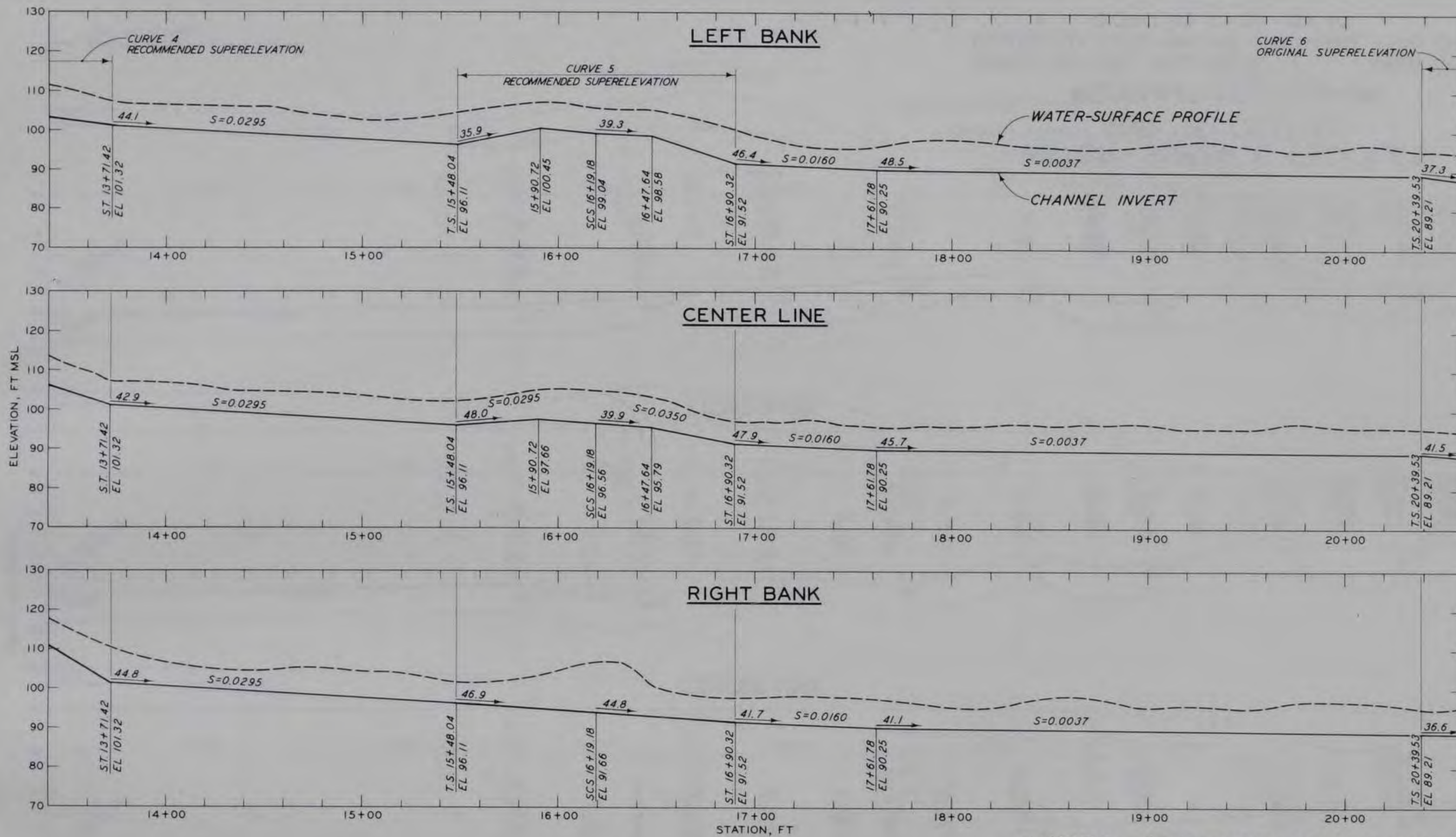


WATER-SURFACE PROFILES AND VELOCITIES

RECOMMENDED DESIGN

MAIN CHANNEL DISCHARGE 4800 CFS
MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
STATIONS 6+20-13+40

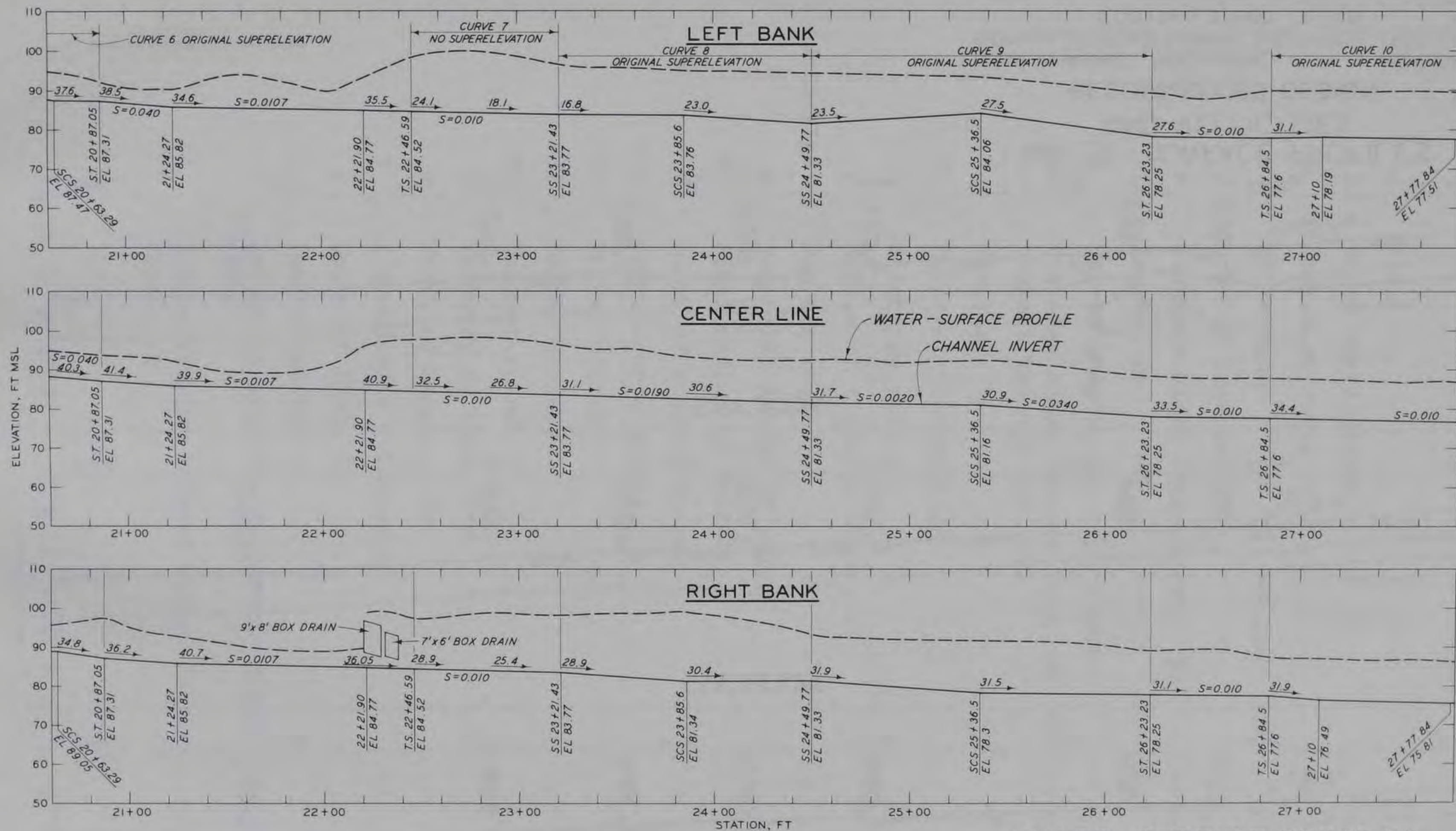
31.1 → DENOTES VELOCITIES IN PROTOTYPE
FEET PER SECOND



WATER - SURFACE PROFILES AND VELOCITIES RECOMMENDED DESIGN

MAIN CHANNEL DISCHARGE 4800 CFS
MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
STATIONS 13+40 - 20+60

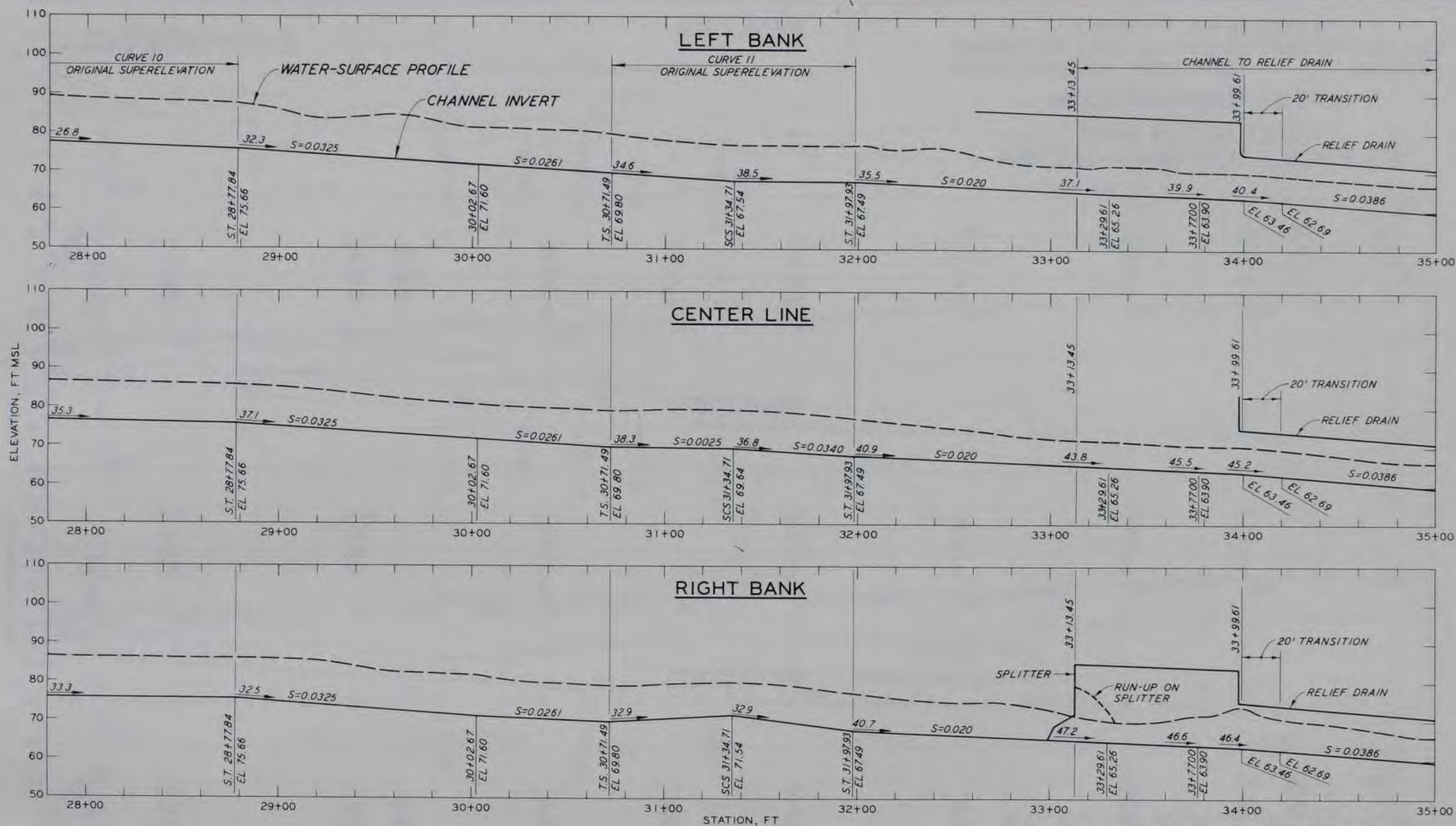
3/1 → DENOTES VELOCITIES IN PROTOTYPE
FEET PER SECOND



WATER - SURFACE PROFILES AND VELOCITIES

RECOMMENDED DESIGN

MAIN CHANNEL DISCHARGE 4800 CFS
 MOANALUA ROAD DRAINS DISCHARGE 1500 CFS
 STATIONS 20 + 60 - 27 + 80



31.1 → DENOTES VELOCITIES IN PROTOTYPE FEET PER SECOND

APPENDIX B: NOTATION

A	Area
c	Curve coefficient
D_c	Degree of curve
E	External
g	Gravity constant
K	Distance along tangent from ST to end of first spiral
L	Length, ft
L_s	Spiral length, ft
LT	Distance along tangent from ST to intersection of tangent through the SCS
n	Manning's n
PI	Point of intersection
Q	Discharge, cfs
r	Radius of a simple curve, ft
r (subscript)	Denotes ratio
R	Beginning radius of spiral
R_c	Final radius of spiral
S	Slope of channel bottom
SCS	Spiral-curve spiral
SS	Spiral spiral
ST	Spiral tangent
TS	Tangent spiral
V	Velocity of flow, fps
W	Width of channel, ft
X_c	x coordinate relating to Y_c
y	Depth of flow, ft
Y_c	Tangent offset
Δ	Change in azimuth of channel center line through a curve
Δ_y	Superelevation between center line and outside of curve, ft