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FINAL II DRAINAGE DESIGN REPORT

FOR
SUPERSTITION FREEWAY (SR 360)
ELLSWORTH ROAD - IRONWOOD DRIVE
PROJECT NO. F-028-1-513
CONTRACT NO. 86-34

Submitted To:
Arizona Statewide Management Consultant
Sverdrup Corporation

May, 1988
(Revised September, 1988)

Prepared For:
Arizona Department of Transportation

Prepared By:
Coe & Van Loo Consulting Engineers, Inc.

CVL Job. No. 0257-100

CVL-8-0095

FINAL I DRAINAGE DESIGN REPORT
FOR
SUPERSTITION FREEWAY
ELLSWORTH ROAD - IRONWOOD DRIVE

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ARIZONA, U.S.A.

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LIST OF SYMBOLS

a	Gutter depression, in.
A	Cross-sectional area of flow, ft^2
B	Bottom width in a trapezoidal channel, ft.
C	Rational equation coefficient of runoff.
d, D	Depth of flow at the curb face, ft.
	Depth of flow in an open channel, ft.
	Diameter of a circular section, ft.
DA	Drainage area, acres
d_c	Critical depth, ft.
DHW	Design headwater depth, ft.
E	Interception efficiency of an inlet.
E_o	Ratio of flow in a chosen width, usually the width of a grate, to total gutter flow.
g	Acceleration of gravity, ft/s/s.
H	Total head loss due to entry, exit and friction losses, ft.
HW	Headwater depth, ft.
H_o	Outlet control water elevation.
i, I	Rainfall intensity, in/hr.
K	Conveyance; the quantity flow rate divided by the square root of the longitudinal slope; $Q/\sqrt{S}$
K_e	Entrance loss coefficient
L	Overland flow length, ft
	Length of inlet, ft.
	Length of pipe, ft.
L_T	Length of curb-opening or slotted drain inlet required for total gutter flow interception, ft.
n	Coefficient of roughness in Manning's equation.
P	Perimeter of a grate opening disregarding bars and neglecting the side against the curb, ft.
Q	Flow rate; discharge from contributing area, ft^3/s.
Q_b, Q_c	Bypass or carryover flow; the portion of total gutter flow which is not intercepted by an inlet, ft^3/s.

Q_i	Intercepted flow; the portion of total gutter flow which is intercepted by an inlet, ft^3/s.
Q_T	Total discharge from contributing area plus bypass flow, ft^3/s.
S, S_o	Longitudinal slope of gutter or channel, ft/ft.
S_e	Equivalent straight cross-slope for a gutter section with a composite cross-slope.
S_x	Pavement cross-slope, ft/ft.
S_w	Cross-slope of a depressed gutter, ft/ft.
S'_w	Cross-slope of a depressed gutter section measured from the normal cross-slope of the pavement, ft/ft.
T	Spread of water on the pavement, ft.
t_c	Time of concentration for use in the Rational Method, min.
TW	Tailwater elevation, ft.
V	Velocity, ft/s.
V	Average velocity in a reach of gutter, ft/s.
V_o	Velocity of flow at which splash-over first occurs over grate, ft/s
W	Width of a grate, ft.; Width of a depressed gutter, ft.
Z	Reciprocal of cross-slope.
Z_w	Reciprocal of cross-slope for gutter ($1/S_w$).
Z_x	Reciprocal of cross-slope for pavement ($1/S_x$).

1.0 INTRODUCTION

1.1 General

Coe and Van Loo Consulting Engineers, Inc., (CVL) has been contracted by the Arizona Department of Transportation (ADOT), under direction from Sverdrup Corporation, Arizona Statewide Management Consultants (ASMC), to provide total engineering services for the design of a four mile segment of the Superstition Freeway. The project, extending from Ellsworth Road to Ironwood Drive, consists of the design of a four lane (ultimate six lane), full access, divided freeway with full diamond interchanges at Ellsworth Road, Signal Butte Road, Crismon Road and Ironwood Drive.

The horizontal alignment will be approximately 200 feet north of the mid-section line within a total of 600 feet of right-of-way. The vertical alignment will be four to six feet above natural ground but will elevate to 22 to 24 feet at the major crossroads.

The purpose of this report is to set forth the drainage criteria and specifications used in the preparation of design plans for both the on-site and off-site drainage facilities and to document design computations.

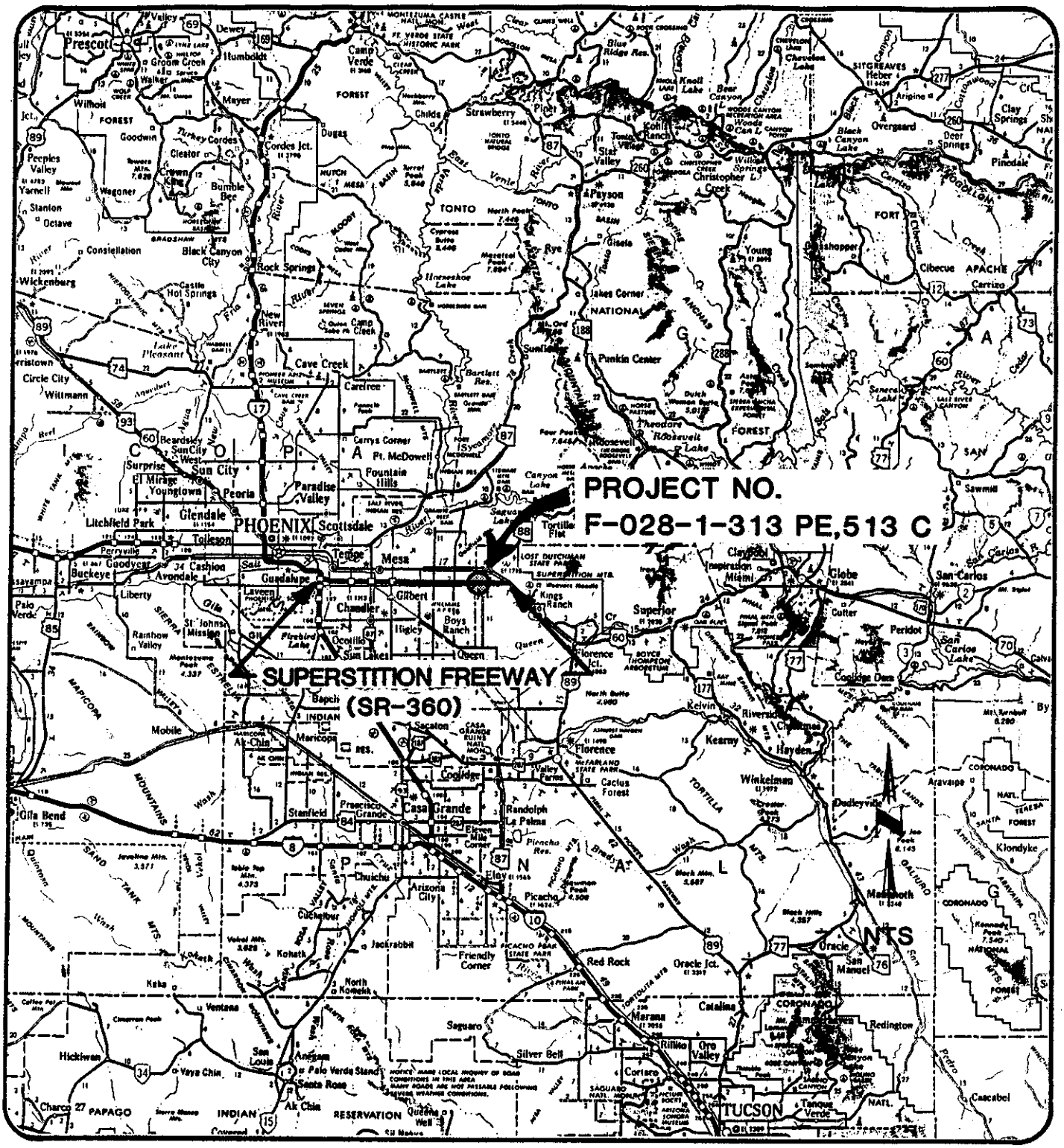
The on-site drainage system design includes the design of all inlets, manholes, sewers, ditches, culverts and erosion controls necessary to dispose of pavement drainage in accordance with ADOT criteria. Off-site hydrology and drainage concepts prepared by A-N West, Inc., subconsultant to Tudor Engineering have been used in the preparation of design plans for the off-site

drainage facilities. Off-site drainage facilities include the construction of drainage interceptor channels, detention basins, outflow structures and cross freeway drainage structures. Recommendations from the A-N West concept report have been reviewed and incorporated, as appropriate, into the overall off-site drainage system which includes channel collection systems, retention/detention basins, outlet structures, culverts, diking and berms.

1.2 Project Location

The Superstition Freeway is an east-west four- and six-lane transportation route serving the rapidly growing East Valley communities of Tempe, Mesa, Chandler, Gilbert and Apache Junction (Figure 1). The freeway runs approximately along the north mid-section line between Southern Avenue and Baseline Road and connects by way of an interchange with Interstate 10. The freeway has been recently completed to Power Road in east Mesa. This project represents one of the three last design segments necessary to extend the Superstition Freeway eastward to its terminus at U.S. 60-80-89 (U.S. 60) in southeast Apache Junction.

The project covered by this contract extends eastward from Ellsworth Road to Ironwood Drive (Figure 2). Two other consultants, URS Corporation, and Tudor Engineering, are responsible for the design segments from Power Road to Ellsworth Road and from Ironwood Drive to U.S. 60 respectively.



SUPERSTITION FREEWAY

ELLSWORTH RD. TO IRONWOOD DR.

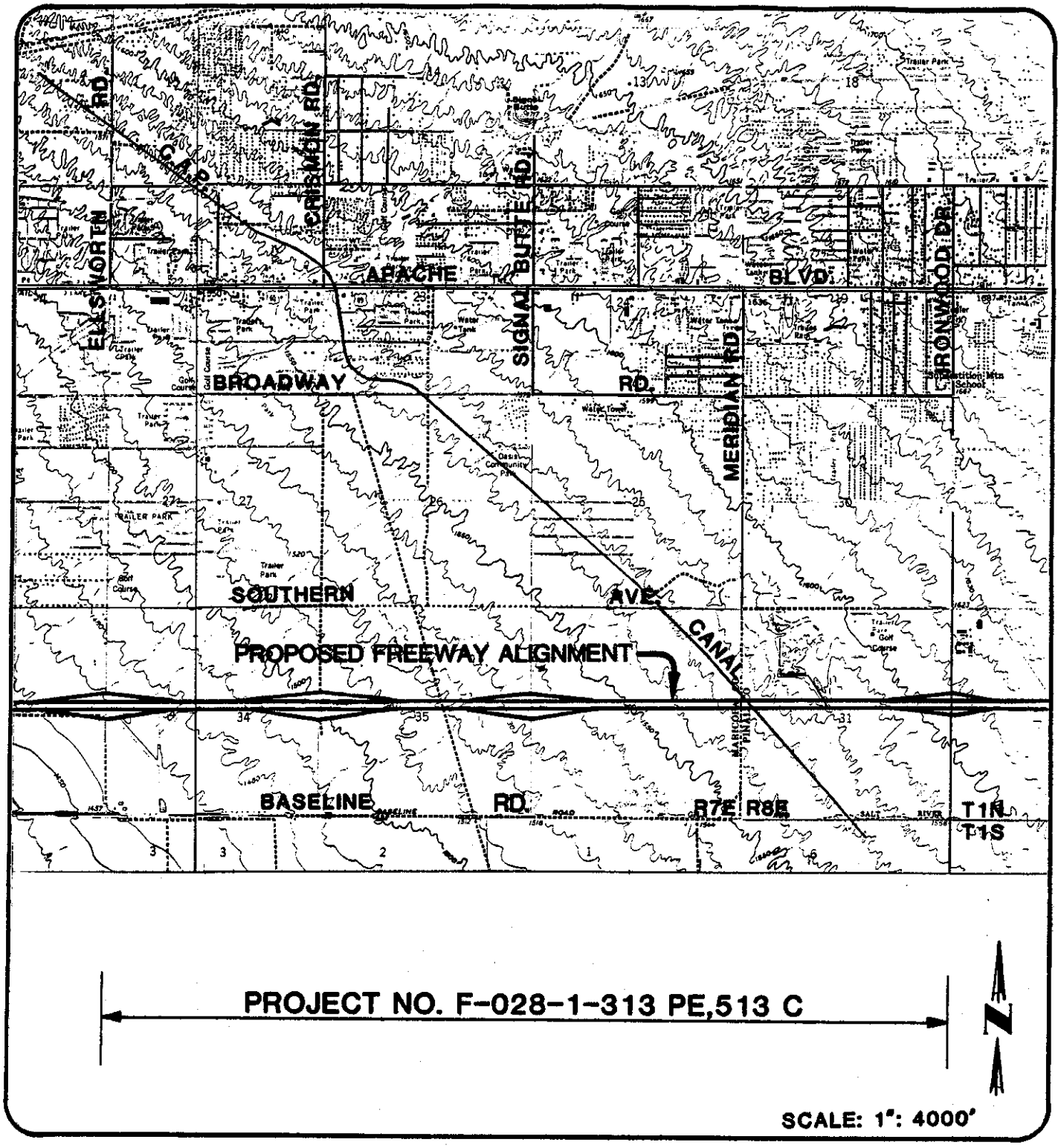
VICINITY MAP

PROJECT NO. F-028-1-313 PE,513 C

COE & VAN LOO

Planning
Civil Engineering
Landscape Architecture
Hydrology
Sanitary Engineering
Surveying
Highway Engineering

FIGURE 1



SUPERSTITION FREEWAY

ELLSWORTH RD. TO IRONWOOD DR.

PROJECT AREA

PROJECT NO. F-028-1-313 PE,513 C

COE & VAN LOO

Planning
Civil Engineering
Landscape Architecture
Hydrology
Sanitary Engineering
Surveying
Highway Engineering

FIGURE

2

1.3 Existing Drainage Features

The Superstition Freeway corridor runs primarily through undeveloped desert. Drainage patterns are generally from the northeast to the southwest with a gradient of approximately 0.8 percent. Much of the watershed does not have a well defined riverine situation since the topography is gently sloping with relatively low relief. The watershed is characteristic of alluvial fans, having ill-defined channels which tend to disperse runoff over a broad floodplain. The natural washes are only two to three feet deep with the result that they have very little conveyance and drainage reaches the North freeway right-of-way alignment primarily as sheet flow. Some relief from flooding in the area has been provided in the form of the Soil Conservation Service (SCS) flood retarding structures, Spook Hill Dam and the Signal Butte Floodway.

The Flood Control District of Maricopa County (MCFCD) has conducted hydrologic studies of this area in order to develop acceptable solutions to the consistent flooding problems experienced in this area. They have recently conducted an Area Drainage Master Study (ADMS) of the area which has resulted in a recommended system of drainage channels and detention basins designed to intercept and convey stormwater runoff to the RWCD floodway. The plan includes the construction of channels parallel to the freeway with detention basins near Ellsworth Road and Signal Butte Road.

2.0 SCOPE OF WORK

2.1 Outline

Concept plan development was divided into both off-site and on-site drainage. A-N West was responsible for conducting all hydrologic analyses, concept plan development, design discharges, locations, preliminary channel, detention basin and culvert sizing for the off-site drainage system. Results from their study have been submitted to the ASMC and recommendations included in their report have been incorporated into the design as appropriate.

On-site drainage concept plan development and final design for both on-site and off-site drainage facilities is the responsibility of the Consultant (CVL). Since the freeway is elevated throughout, except near Ellsworth where it becomes depressed in order to meet the westerly project, no pumping stations will be necessary. The freeway, while above ground, will have continuous curb and gutter, and thus catch basins will be required throughout to intercept pavement, median and crossroad drainage. On-site drainage has been designed to either outfall into a storm drainage collection system or directly into the off-site drainage channels and natural washes.

This project includes the design of on-site and off-site drainage collection and disposal facilities. The Consultant shall be responsible for the work outlined in this Section. The work shall conform to the standards, criteria, and requirements of this Scope of Work.

Design of this project will be coordinated with the other consultants on the adjoining sections of the Superstition Freeway and with the Red Mountain Freeway and Southeast Loop Freeway. ADOT has acquired all necessary right-of-way for the freeway. Additional right-of-way will be necessary where off-site detention basins have been sited.

2.2 Off-Site Drainage Scheme

The firm of A-N West, as a subconsultant to Tudor Engineering Company, will be responsible for a comprehensive drainage plan covering the Superstition Freeway from Power Road to U.S. 60. A-N West shall provide concepts, data, and design criteria to the Consultant for the off-site drainage elements of the project. The Consultant shall develop the designs for the off-site drainage facilities based on the information provided by A-N West.

3.0 DESIGN PROCEDURES

3.1 Outline

Drainage design procedures have been developed for the on-site drainage system for this project and are intended as a guideline and aid as final design progresses. These guidelines have been adapted from standardized ADOT procedures, and the "Drainage Design Criteria/Guidelines" prepared by the ASMC (Appendix I-A), in order to define specifications relevant to this project. The drainage design criteria thus established for this project are summarized in Appendix I-B. Standard procedures have been simplified and general equations and charts have been developed as an aid in efficiently completing the drainage design. The methods intended to be used and their derivations are summarized in Appendix II-D.

3.2 Pavement Drainage

3.2.1 Freeway Mainline

The freeway is to be designed as a four-lane facility with ultimate expansion, within the central median, to six lanes. The pavement drainage will be designed with the ultimate pavement width in mind, ignoring the central median presently being designed. Design charts have been developed for the special non-hazardous curb to be utilized using procedures as summarized in Appendix II-D. These charts have been developed using standard methods and procedures described in HEC No. 12 and are intended for use during the preliminary and final design stages. Catch basins will be spaced according to maximum allowable pavement spread and geometric considerations.

A combination of slotted drain and special catch basins are proposed for stormwater interception. Catch basin and storm drain design methods and procedures using design charts and tables presented in Appendix II-C are detailed in Appendices II-F and II-G.

3.2.2 Crossroads

Four major mile streets running north-south cross the freeway alignment within this design segment; namely Crismon Road, Signal Butte Road, Meridian Road and Ironwood Drive. Crossroad drainage is primarily from north-south. Drainage will be provided for the crossroads within the ADOT right-of-way limits. Design will be such as to prevent interference with traffic operation at the interchanges. This will entail providing sufficient catch basins on the north side in order to allow no more than 1 cfs of drainage from crossing the freeway ramp approaches.

The freeway on- and off-ramps grade downward toward the crossroads except at Meridian Road where there is no interchange. Ramp catch basin spacing are designed to prevent drainage from spreading onto the crossroad. Local drainage criteria are adhered to where appropriate. Where possible, catch basins discharge either directly or through the use of storm drains into the off-site drainage interceptor channel. Design follows the criteria and procedures presented in Appendices I-B and II-D.

3.3 Median Drainage

The freeway is designed as a four-lane facility with the expansion capability, within the central median, for two additional lanes to an ultimate design of six lanes. In the

interim, a landscaped median will be provided. Runoff that results within the median will be drained by median catch basins. Median dikes are provided on the downstream side of median catch basins to allow for ponding and head build up over the catch basin. Under the ultimate condition of six lanes the median will be paved over and the median catch basins rendered inoperative. Median catch basin design is based upon the criteria set forth in Appendix I-B and the standard computational methods summarized in Appendix I-D.

3.4 Storm Sewer

The storm sewer system has been designed to handle the quantities of flow as determined by the inlet computations. Storm drainage pipes are limited to a minimum of 24 inches in diameter for connector pipes and 24 inches in diameter for the mainline. Where continuous sewer runs are justified, inlet flow rates are adjusted to account for sewer travel time, if appropriate.

Pipe sizes are based upon a full flow condition, for above grade drainage, where the design frequency is 10-year. For depressed roadway sections, where the design frequency is 50-year, the pipes are sized based upon pressure flow in accordance with the design criteria. Hydraulic Grade Lines (HGL) are computed and shown on the plans for both pressure and non-pressure flow conditions. The HGL is computed using the pipe and channel flow program developed by the Los Angeles County Flood Control District,"Water Surface and Pressure Gradient" (WSPG). Details of this program and other design procedures for sewer design are summarized in Appendix I-Dand II-D.

4.0 ON-SITE DRAINAGE PLAN

4.1 Outline

An overall concept plan for the on-site drainage was developed based upon the design procedures established in Section 3.0 and the initial vertical alignment. Due to changes in the vertical alignment and catch basin spacing criteria, the number and spacing of catch basins presented in the Initial Drainage Design Report have changed. Catch basin locations and spacings shown in the earlier report were also established based upon simplified assumptions. The final design now presented is based upon better information and more detailed computations.

4.2 Drainage Scheme

In the Initial Drainage Design Report, an economic comparison was conducted in order to evaluate the merits of slotted drains versus catch basins for a one mile design segment. A concept design plan for both alternates was prepared and the cost of each system compared, this was considered necessary due to the continually changing bid prices for slotted drains. The results of this comparison confirmed that the use of slotted drains designed to provide 100 percent drainage interception is the most cost effective solution; subsequent design has thus been based upon the use of slotted drains throughout the project.

An on-site drainage concept plan utilizing slotted drains throughout was prepared for each mile segment and presented in the Initial Drainage Design Report. Since development of the on-site drainage concept, there has been a change in the design for maximum allowable spread from 10.0 feet (shoulder width) to 16.0

feet (shoulder width plus 1/2 driving lane). This change has resulted in a reduction in the number of catch basins required; the general drainage concept, however, remains unchanged. Changes in design criteria from the Preliminary plan submittal stage have resulted in a subsequent increase in catch basins along the on- and off-ramps. Ramp drainage spread criteria, which allow only for drainage on the shoulder, are now adhered to throughout the ramp taper rather than terminating at the gore paving areas as previously submitted.

Catch basin sizes and locations presented in the design have been based upon maximum allowable spread limits and other geometric considerations. Mainline freeway drainage is intercepted at the upslope side of ramp gore areas in order to prevent concentrated flow from crossing the paved ramp areas.

Catch basins are located in sump areas with flanking inlets on each side. The off-site drainage channels and cross freeway culverts are utilized as an outfall for the catch basins where possible. In this way the number of storm drainage outlets emerging from the freeway on the south side are limited. On the north side of the freeway, local runoff from south of the off-site channel system is intercepted by a toe of slope swale and conveyed to a convenient location where it is collected by median-type catch basins and piped either to the south side of the freeway or to the off-site interceptor channel.

The freeway transitions to a depressed section at the west project limits at the Ellsworth Road interchange. In this area a storm sewer has been designed by URS; final sizing and location

has been coordinated with them. Catch basins within this section are designed for a 50-year storm and tie into the storm sewer in the URS design section.

5.0 OFF-SITE DRAINAGE PLAN

5.1 Outline

The firm of A-N West, Inc., as subconsultant to Tudor Engineering was responsible for the overall off-site drainage concepts and coordination between each of the three design segments. As part of their contract, A-N West developed hydrology for the off-site flows reaching the freeway north right-of-way. Using the existing condition hydrology they developed a drainage concept plan which is detailed in a report entitled "Superstition Freeway, Comprehensive Off-Site Drainage Plan". Information presented in this report has been utilized by CVL to develop the final design. Design discharges and detention basin storage volumes have been refined and better information has facilitated the sizing and location of drainage channels and cross drainage culverts.

5.2 Drainage Scheme

Natural washes that approach the future freeway alignment are ill-defined with generally low capacity. The result is that during a large flood event drainage reaching the freeway will occur primarily as sheet flow. The future drainage system, which is sized for the 100-year, 24-hour event, consists of a series of concrete-lined interceptor channels that will flow from east to west, either directly discharging through culverts under the freeway or being directed toward a detention basin system (See Plate 1).

Detention storage is provided in order to mitigate the

downstream effects of a concentrated point discharge. Basin discharge outlet is directed toward existing washes of significant size.

5.3 Hydrology

The off-site hydrology for the entire freeway was developed by A-N West using the Corps of Engineers computer program "HEC-1, Flood Hydrograph Package." In this rainfall-runoff model the SCS Type II rainfall distribution was used to model runoff for the 2, 10, 50 and 100-year 24-hour precipitation events. While the final design has been modified somewhat from that originally proposed by A-N West in their concept report the results from the original hydrologic model remain essentially the same and have been recreated in this report. Any changes made have been as a result of structural changes, no modifications have been made to hydrologic parameters.

The final drainage layout and hydrologic routing model are shown schematically on Plates 1 and 2. Results from the computer model input and output are summarized in Appendix III-A.

5.4 Interceptor Channels

Due to the alluvial nature of the upslope watershed, drainage reaches the freeway alignment primarily as sheet flow. As a result, the drainage scheme proposed by A-N West, and incorporated in the final design, consists of a series of interceptor channels parallel to the freeway alignment. These collect and concentrate sheet flow.

Due to the susceptibility of soils in the area to erosion, concrete lined channels were selected. This is in keeping with

previous design segments of the Superstition Freeway. The north side of the interceptor channel lining will extend up to meet existing ground in order to minimize bank erosion and headcutting that might otherwise result from inflowing washes. When significant washes traverse the channel alignment, the north channel lining has been lowered. The channel lining height on the south side is based upon the design flow depth plus applicable freeboard requirements. Soil erosion on the south side will be minimized due to a five-foot level bench.

Design flow depths for the channels and spillways were initially established using normal flow depth computations and then checked using backwater techniques. Water surface profiles have been modeled using either the Corps of Engineers, HEC-2, or the program "Water Surface and Pressure Gradient" (WSPG), developed by the Los Angeles County Flood Control District (Appendix I-D). Results from these computations are documented in Appendix III-B.

5.5 Detention Basins

Two detention basin systems have been designed for the attenuation of peak discharges. Sergent, Hauskins and Beckwith (SHB), geotechnical and soils engineers for this project, performed a slope stability analysis assuming a sudden drawdown within the basins and they concluded that a maximum side slope of 5:1 (horizontal to vertical) would be acceptable. The basins are primarily excavated below natural ground but a maximum six-foot high embankment is used on the downslope side of each basin. In their geotechnical report SHB recommended that soil beneath the embankment be overexcavated due to its collapsible nature.

5.5.1 Ellsworth Road

The Ellsworth Road detention basin provides 617 acre-feet of storage up to the emergency spillway elevation of 1474.0 with a maximum depth of 19 feet. Drainage that reaches the freeway alignment from a point 1800 feet west of Signal Butte Road to Ellsworth Road will be intercepted by a collection channel and conveyed westward to this basin.

Additional inflow to the basin is intercepted by a collector channel parallel to Ellsworth Road, presently under design by the Maricopa County Highway Department.

Due to right-of-way considerations, the final basin configuration has evolved from the original concept plan to that presented in the final design (Plate 1).

Outlet from the basin is controlled through a 48-inch pipe with a manually operated headgate. This headgate, while designed to remain partially open at all times, may be opened up to allow for a quicker release rate after a major flood event has passed. Drainage from this basin is directed westward into the URS freeway design section from which it eventually outlets to the Sossaman drainage channel.

5.5.2 C.A.P. Canal

The final design for a detention basin system at the C.A.P. Canal differs significantly from that proposed in the original concept study report. Reasons for these changes are fully documented in a report by CVL entitled "Offsite Drainage Alternatives, Plan Development Report." The system consists of two adjacent detention basins, each operating independently of

the other. Each basin collects drainage outflow that results from five C.A.P. overchutes.

The north basin intercepts drainage that results from three overchutes located on the north side of the Southern Avenue alignment. This basin provides 668 acre-feet of storage to the emergency spillway at elevation 1555.0. A concrete lined collector channel parallel to the C.A.P. Canal is designed to intercept drainage that results from two overchutes and convey it under Southern Avenue into the north basin through box culverts. This system was designed using the side spillway concept as discussed in detail in the Bureau of Reclamation's publication "Design of Small Dams." A third overchute will be piped directly into the basin using five 72-inch diameter pipes. Both these pipes and box culverts for the interceptor channel are proposed to be constructed by the MCHD with improvement plans for Southern Avenue. Details have yet to be worked out through an Inter-Agency agreement.

Outlet from the western basin is through a single 72-inch pipe discharging into an interceptor channel 50 feet south of the north right-of-way line. This is directed to an outfall approximately 1800 feet west of Signal Butte Road.

The second detention basin lies south of the aforementioned basin and adjacent to the C.A.P. Canal. This basin has a capacity of 300 acre-feet to an emergency spillway elevation of 1560.0. Overflow from two C.A.P. overchutes is intercepted directly and conveyed into the basin using spillways.

Drainage outlets from this basin through a single 72-inch pipe. The basin outlet elevation is controlled by the existing wash outlet elevations and the freeway pavement grades.

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APPENDIX I

A. DRAINAGE DESIGN CRITERIA GUIDELINES - SVERDRUP (ASMC)

SECTION 102

DRAINAGE DESIGN CRITERIA/GUIDELINE

102.1 DESIGN REFERENCES

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U.S. Department of Transportation, Federal Highway Administration, "Hydraulic Design of Highway Culverts," Hydraulic Design Series No. 5, latest edition (HDS No. 5).

U.S. Department of Transportation, Federal Highways Administration, "Hydraulic Design of Energy Dissipators for Culverts and Channels," Hydraulic Engineering Circular No. 14, latest edition. (HEC No. 14)

102.2 HYDROLOGIC DESIGN

1. Peak Rates of Runoff

Reference ADOT Manuals and data sheets included in manuals.

a) For Urban areas

(1) Use Rational Method for areas under 0.125 square miles (80 acres) and pavement and median drainage.

(2) Use TR-20 or TR-55 method as developed by the Soil Conservation Service or HEC-1 Flood Hydrograph Package as developed by the U.S. Army Corps of Engineers for areas greater than 0.125 square miles.

b) Non-Urban Areas

(1) Use Rational Method for areas under 0.125 square miles (80 acres) and pavement and median drainage.

(2) Use TR-20 or TR-55 method as developed by the Soil Conservation Service or HEC-1 Flood Hydrograph Package as developed by the U.S. Army Corps of Engineers for areas greater than 0.125 square miles.

c) Design should consider land development expected in the area for 20 years in the future.

2. Frequencies

a) The following frequencies are applicable:

Type of Structure	Type of Project: Interstate	Primary	Secondary
Bridge	50 yr.**	50 yr.**	50 yr.*
Culvert	50 yr.**	50 yr.**	25 yr.
Storm Sewer	10 yr.	10 yr.	10 yr.
Storm Sewer for Depressed Section	50 yr.	25 yr.***	10 yr.***
Pavement Drainage	10 yr.	10 yr.	10 yr.
Median Drainage	50 yr.	50 yr.	25 yr.

* A lesser value may be used when conditions warrant. Justification shall be included in the report.

** The flood of record should be used if greater than the 50 year event.

*** A higher value may be used where conditions warrant. Justification shall be included in the report.

b) In cases where the highway encroaches into a regulatory floodway, the 100 year design frequency shall be used.

c) The design frequencies shall be reviewed to assure compliance with Federal Highway Program Manual, Volume 6, Chapter 7, Section 3, Subsection 2.

102.3 PAVEMENT DESIGN

This section is limited to the drainage of pavements where an underground sewer system is not required and where pavement runoff must be concentrated at the roadway shoulder to prevent erosion of the embankment face.

1. Storm frequency shall be in accordance with criteria in Section 1.2, Design Frequency, ADOT Manual I, pages 1 and 2.

2. Storm runoff shall be calculated by the Rational Method.

3. Allowable ponding widths shall be as follows:

Roadway Type	Maximum Spread	Frequency
Rural 4-lane divided	Lt. shoulder width Rt. shoulder width plus 1/2 adjacent traffic lane width	10 years
Urban 4 or 6 lane divided by raised median	Lt. gutter width plus any shoulder width Rt. shoulder, parking or distress lane width plus 1/2 adjacent traffic lane width	10 years
4 or 6-lane undivided	Shoulder, parking or distress lane width plus 1/2 adjacent traffic lane width	10 years
2-lane undivided	Gutter and/or shoulder parking or distress lane width	10 years
22' or 24' ramps (Incl. accel. & decel. lane)	Left 2' Right 8'	10 years

4. Embankment curb shall be used at the edge of paved roadways on fills where storm water cannot be permitted to run down and erode the embankment face.

5. Hydraulic Capacity Charts have been developed for standard ADOT embankment inlets and shall be used in the design. Reference ADOT Standards C-04.10 (Formerly C-4.01) and C-04.20 (Formerly C-4.02).

   The hydraulic capacity charts for these standards have the clogging factors incorporated into them and no additional reduction should be made.

6. Inlets on grade

   Portion of flow permitted to by-pass inlet and be picked up at succeeding inlets downstream.

7. Inlets at Sag

   Inlets must be sized to intercept all of the flow. No flow will be permitted to overtop the curb. If the inlet capacity in the sag is less than the approach flow, then additional inlets shall be placed upstream to reduce the flow at the sag.

8. Spillways and Downdrains:

   a) Use between inlets and toe of slope and in accordance with ADOT Standards C-04.10 (formerly C-4.01), C-04.20 (Formerly C-4.02) and C-04.40.

   b) The curb opening inlets on grade and in sags shall be spaced such that curbs are not overtopped and the pavement spread remains within the specified limits.

   c) If possible, space the curb opening limits to eliminate water by-passing. This is not required, but is preferable.

   d) Downdrains will be used where embankment slopes are steeper than 4:1 and where spillways will be visible from the main roadway.

   e) Spillways will be used where embankment slopes are 4:1 or flatter.

9. All computations to be performed on ADOT Pavement Drainage Design Sheets contained in ADOT Manuals.

102.4 MEDIAN DRAINAGE

1. The storm runoff from medians will be removed by median inlets or standard culverts.

2. Storm frequency shall be in accordance with criteria in Section 1.2, Design Frequency, ADOT Manual I, pages 1 and 2.

3. Storm runoff shall be calculated by the Rational Method.

4. The maximum allowable ponding depth in the median shall not exceed an elevation of 0.5 feet below the top of the subgrade at the edge of pavement.

5. Median dykes will be required at the downstream side of all median drains except where the inlet is located in a sag. The top of the median dyke should be at least 0.5 feet higher than the design highwater elevation of the inlet.

6. Pave median when velocity is excessive and erosion is a problem.

7. Hydraulic capacity charts have been developed for standard ADOT median inlets and shall be used in the design. Reference ADOT Standards C-15.30 (Formerly C-15.08), C-15.80 (Formerly C-15.09) and C-15.90 (Formerly C-15.10).

   The hydraulic capacity charts for these standards have the clogging factors incorporated into them and no additional reduction should be made.

8. All computations are to be performed on ADOT Median Drainage Design Sheets contained in the ADOT Manuals.

102.5 STORM SEWER SYSTEM

1. The storm sewer system shall consist of a system of inlets, conduits and other appurtenances which are designed to collect and convey storm runoff from the roadways and adjacent contributory drainage areas to an outlet.

2. Storm frequency shall be in accordance with criteria in Section 1.2, Design Frequency, ADOT Manual I, pages 1 and 2, with the exception of underpasses or other depressed roadways where ponded water can be removed only through a storm sewer system. For this exception, the storm frequency shall be 50 years.

3. Storm runoff shall be calculated by the Rational Method.

4. The allowable ponding width shall be in accordance with criteria in Section 2.2, Pavement Design, Item 3 of part 102.3 of this section.

5. Hydraulic capacities of the standard ADOT inlets shall be determined utilizing the general equations.

6. The following factors shall be applied to grate, curb opening and combination inlets due to clogging:

   a) Grates

(1) Sump Conditions

(a) Orifice Flow - actual area = 2.0 x required area

(b) Weir Flow - actual Perimeter = 2.0 x required perimeter

(2) Continuous Grade Conditions - actual length of opening = 2.0 x required length or greater

b) Curb Opening Inlets

(1) Sump Conditions - actual length of opening = 1.25 x required length or greater

(2) Continuous Grade Conditions - actual length of opening = 1.25 x required length or greater

c) Combination Grate and Curb Opening - ADOT Standard C-15.10 Catch Basin, Type 1 and 2

(1) Sump Conditions

(a) Orifice Flow - actual area = 1.0 x required area of grate only

(b) Weir Flow - actual perimeter = 1.0 x required perimeter of grate only

(2) Continuous Grade Conditions - actual length of opening = 1.0 x required length of curb opening only

d) Standard C-15.40 Catch Basin, Type 5

(1) Sump Conditions

(a) Orifice Flow - actual area = 1.0 x required area of grate only

(b) Weir Flow - actual perimeter = 1.0 x required perimeter of grate only

(2) Continuous Grade Conditions - actual curb opening length upstream from grate = 1.25 x required length

e) Slotted Drains

(1) Sump Conditions - actual length of opening = 2.0 x required length

(2) Continuous Grade Conditions

(a) Parallel to Flow - actual length of opening = 1.5 x required length

(b) Perpendicular to Flow - do not use

7. Urban and freeway closed drainage systems shall be designed for reinforced concrete pipe. An 18-inch minimum pipe size shall be used for laterals and a 24-inch minimum pipe size shall be used for trunk lines. A hydraulic profile of the storm sewer system shall be required to assure the system will perform as designed. At all inlet locations the hydraulic grade line shall be at least 0.5 feet below the bottom of the inlet or grate.

8. Catch Basins

a) All catch basins and grates shall conform with ADOT Standards, C-15.10 thru C-15.90.

b) Catch basins shall be spaced such that curbs are not overtopped and the pavement spread remains within the specified limits.

9. All computations shall be shown on ADOT standard design forms contained in ADOT Manuals.

a) Runoff Calculation Sheet - all design data and hydrologic calculations

b) Inlet Calculations Sheet - all inlet design data and calculations

c) Storm Sewer Calculation Sheet - all storm sewer design data and calculations

10. Depressed Roadways

a) Design the storm sewer for a 50-year frequency.

b) Determine the elevation of the 50-year hydraulic grade line (HGL) and check to see that the HGL is at least 0.5 feet below the bottom of the inlet or grate at all roadway inlets.

c) If the 50-year HGL elevation is less than 0.5 feet below the elevation of the bottom of the inlet or grate of any roadway inlet, adjust the conduit sizes or flow line elevations as necessary to lower the HGL elevation at that point.

d) If revisions have been made, recheck the 50-year HGL to determine the effect on the remainder of the system.

e) If the storm sewer terminates at a pump station, the 50-year HGL must consider the water surface elevation in the pump station.

f) The 50-year HGL shall be shown on the final profiles.

102.6 CROSSROAD CULVERTS

1. Storm frequency shall be in accordance with criteria in Section 1.2, Design Frequency, ADOT Manual I, pages 1 and 2.

2. Storm water runoff shall be calculated utilizing the correct method for the conditions as stipulated in Section 102.2 Hydrologic Design Methods, Project Design Guidelines, page I-18.

3. Calculate size and type of structure in accordance with HDS No. 5. The maximum allowable headwater shall not exceed an elevation of 0.5 feet below the top of subgrade at the edge of pavement.

4. Pipe culverts shall be designed for corrugated metal pipe. However, all viable alternative materials shall be listed in the pipe summary tables in the construction drawings, with smooth pipe and corrugated pipe listed with the same diameter. A 24-inch minimum pipe size shall be used for all culverts.

5. The culvert inlet shall be as close as possible to the natural stream bed. Any culvert having an invert elevation more than six inches below the natural stream profile shall be assumed to have only the waterway opening above the stream bed profile for hydraulic capacity calculations.

6. Outlet Protection

   a) Structures in range and desert areas, with drainage areas less than 0.1 square miles, will not require outlet protection unless specifically requested at the field review.

   b) Structures in urban areas, with drainage areas less than 0.1 square miles, will be analyzed for potential scour and protection designed accordingly.

   c) All structures in areas with drainage areas greater than 0.1 square miles shall be designed with outlet protection. The following parameters are suggested for determining the type of outlet protection required. The Consultant shall be responsible for the design and type of material used.

Ratio of Outlet Velocity to Natural Stream Velocity	Outlet Protection
Less than 1.5	No protection required
1.5 to 2.0 with outlet velocity less than 10 fps	Dumped rock riprap
1.5 to 2.5 with outlet velocity between 10 and 15 fps	Wire-tied rock riprap
Greater than 2.5 or outlet velocity greater than 15 fps	Energy dissipator or consider larger culvert

Use rock density of 140 lb/cu. ft. in the design of graded riprap. The dumped rock riprap shall be designed in accordance with HEC No. 15.

d) For outlet flow velocities greater than either 2.5 times the natural stream velocity or 15 feet per second, an energy dissipator should be considered. The design shall be in accordance with HEC No. 14.

7. The 100-year event shall be analyzed for potential damage to upstream property, roadway, and channel erosion for all crossroad culverts.

102.7 CHANNEL AND DITCH

1. Hydraulic design shall be in accordance with ADOT manuals, Hydraulic Engineering Circulars prepared by the Federal Highway Administration, and sound engineering practice.

2. The suggested minimum freeboard for improved channels shall be as follows:

   a) For channels with flows having a Froude Number equal to or greater than 0.86, use 0.20 x (depth + $V^2/2g$)

   b) No freeboard less than 1.0 foot

3. Paving shall be used where necessary for erosion protection.

102.8 EROSION CONTROL

1. Temporary erosion control methods shall be employed during construction to control erosion and sediment until the permanent protection is provided. The types of protection are generally as follows:

   a) Direct Protection of Ground Surface - ground cover, soil stabilization or riprap

APPENDIX I

B. PROJECT SPECIFIC DRAINAGE DESIGN CRITERIA - CVL

PROJECT SPECIFIC

DRAINAGE DESIGN CRITERIA

A. General

These criteria have been compiled from ADOT standard procedures in conformance with similar freeway design jobs. They are intended as a summary of standards to be utilized for the Superstition Freeway design from Ellsworth Road to Ironwood Drive.

The drainage system design for the Superstition Freeway shall include all inlets, manholes, sewers, ditches, culverts, or other hydraulic and erosion control appurtenances required to:

1. Properly dispose of storm runoff disrupted or generated by the Freeway and its associated construction.

2. Protect the roadway and slopes from damage by erosion.

3. Maintain clear traffic lanes for the design storm.

B. Applicable Design Standards

The following publications are to be used in conjunction with these criteria as guides in developing the design plans for this project.

Arizona Department of Transportation Publications:

1983 Construction Standard Drawings
1983 Structures Section Standard Drawings

Drafting Guides for use in Office and Field - 1984

Structures Section - Reinforced Concrete Box Culvert Manual, 1981

Hydrologic Design for Highway Drainage in Arizona - 1968

Hydrologic and Hydraulic Training Session Manual - October 16-17, 1972, December 1973.

Federal Highway Administration (FHWA):

FHPM - Vol. 6, Chapter 7, Sec. 3, Subsec. 2 - "Hydraulic Design of Highway Encroachments of Flood Plains."
Hydraulic Charts for the Selection of Highway Culverts, HEC No. 5, Dec. 1965
Capacity Charts for the Hydraulic Design of Highway Culverts, HEC No. 10, March 1965
Drainage of Highway Pavements, HEC No. 12, March 1984
Hydraulic Design of Improved Inlets for Culverts, HEC No. 13, Aug. 1972

Hydraulic Design of Energy Dissipators for Culverts and Channels, HEC No. 14, Nov. 1975
Federal Highway Administration (FHWA) (Cont.):
Design of Stable Channels with Flexible Linings, HEC No. 15, March 1977
Highways in the River Environment - Hydraulic and Environmental Design Considerations, May 1975

U. S. Army Corps of Engineers (COE):

HEC-1 Flood Hydrograph Package - Computer Program, Sept. 1981
HEC-2 Water Surface Profiles - Computer Program, Sept. 1982

Los Angeles County Flood Control District (LACFCD):

Water Surface and Pressure Gradient & Hydraulic Analysis System (WSPG) - Computer Program F0515P, April 1979

Arizona Statewide Mangagement Consultant (ASMC):

Scope of Work
Project Design Memorandum
Project Design Guidelines

C. **Pavement Drainage**

1. Method used to estimate design flow - Rational Method.

2. Design Frequency - Depressed (50-year)
   - Elevated (10-year)

3. Times of Concentration:

   a. 10 minutes minimum or sum of overland and gutter flow time if more than 10 minutes.
   b. No watershed velocity less than 1.0 ft/sec. shall be used.

4. Rainfall Intensity - Chart I Appendix II-C (As developed from Precipitation-Frequency maps of Arizona and methods presented in Weather Bureau Technical Paper No. 40).

5. Runoff Coefficients

   a. Paved Surfaces.....0.95
   b. Highway Slopes and Ditches (Unpaved).....0.5
   c. Urban Residential Districts.....0.4 - 0.6
   d. Parks and Recreation.....0.3 - 0.4
   e. Cultivated Areas.....0.2 - 0.4

6. Method to be used for catch basin design:

   Publications:
   a. "Median Drainage Design." ADOT, October, 1972.
   b. "Pavement Drainage Design." ADOT, October, 1972.
   c. "Storm Sewer System Design." ADOT, October, 1972.

Publications (Cont.):

d. "Hydrologic and Hydraulic Design Methods and Criteria." ADOT, October, 1972.
e. "Hydrologic Design for Highway Drainage in Arizona." ADOT, December, 1968 (Rev. March, 1969).
f. "Drainage of Highway Pavements; HEC No. 12, FHWA, March, 1984.

Median Drainage:

1. Median dikes to be constructed in accordance with Std. C-03.10, Type B. Dike elevation a minimum of 1.5' above grate elevation, or 0.5' above design high water elevation of inlet, whichever is greater.
2. High water and dike elevation not to exceed top of subgrade.

Grates:

1. Sump Conditions:
   a. Orifice Flow: Actual Area = 2.0 x required area
   b. Weir Flow: Actual Perimeter = 2.0 x required perimeter
2. Continuous Grade Conditions:
   a. Actual length of opening = 2.0 x required length or greater

Curb Opening Inlets:

1. Sump Conditions:
   a. Actual length of opening = 1.25 x required length or greater
2. Continuous Grade Conditions:
   a. Actual length of opening = 1.25 x required length or greater

Combination Grate and Curb Opening:
ADOT Standard C-15.10 catch basin, Type 1 and 2.

1. Sump Conditions:
   a. Orifice Flow: Actual area = 1.0 x required area of grate only
   b. Weir Flow: Actual perimeter = 1.0 x required perimeter of grate only
2. Continuous Grade Conditions:
   a. Actual length of opening = 1.0 x required length of grate only

ADOT Standard C-15.40 Catch Basin, Type 5:

1. Sump Conditions:
   a. Orifice Flow: Actual area = 1.0 x required area of grate only.
   b. Weir Flow: Actual perimeter = 1.0 x required perimeter of grate only.
2. Continuous Grade Conditions:
   a. Actual curb opening length upstream from catch basin = 1.25 x required length
   b. Actual length of grate = 1.0 x required length of grate only

Slotted Drains

1. Sump Conditions:
   a. Actual length of opening = 2.0 x required length.
2. Continuous Grade Conditions:
   a. Actual length of opening = 1.50 x required length.

7. Mannings "n"

   a. Concrete pavement and shoulder.....0.016
   b. Asphaltic concrete pavement and shoulders....0.016
   c. Unpaved median.....0.025

8. Allowable Spread - The maximum allowable water spread on pavement shall be as follows:

Roadway Type	Maximum Water Surface Width	*Storm Frequency
Urban 4 or 6 lane Divided	Lt.-N/A Rt.-16.0'	10-year
22' - 28' ramps (including acceleration and deceleration lanes)	Lt.-2.5'(Non-hazardous curb) Rt.-8.0'	10-year
Crossroad	Lt.-N/A Rt.-14.0'	10-year

   * 50-year for underpasses or other depressed roadways where ponded water can be removed only through a storm drain system.

9. Curb and gutter
   a. Freeway Mainline — Non-hazardous
   b. Freeway Ramps — Non-hazardous
   c. Cross Roads — C-05.10, Type A, h=7"

10. Maximum cross pavement drainage - 1 cfs.

D. **Storm Sewers**

1. Method used to estimate design flow - Rational Method.

2. Design Frequency

   a. 10-year flowing just full.
   b. 50-year storm hydraulic gradient shall not exceed an elevation six inches below the low steel of a catch basin grate.

3. Time of Concentration
   a. Time to first pavement inlet - 10 minutes minimum.

b. Time of concentration for overland flow - Sum of overland and gutter flow time if more than 10 minutes.
c. Sewer flow time to be computed by Manning's Equation.

4. Rainfall Intensity - Chart enclosed (As developed from Precipitation-Frequency Maps of Arizona and methods presented in Weather Bureau Technical Paper No. 40).

5. Method for hydraulic analysis - Flowing just full using Manning's Equation; Pressure flow using computer program WSPG.

6. Manning's "n"

   a. Concrete Pipe.....0.012
   b. Box Culverts.....0.015
   c. Corrugated Metal Pipe.....0.024
   d. Cast Iron Pipe.....0.013
   e. Steel Pipe.....0.011
   f. Cast-in-place concrete pipe.....Not Used

7. Minimum Velocity - 3 feet per second desirable for design flow.

8. Minimum Pipe Size - 24" for all pipe.

9. Maximum length of pipe between manholes or access points.

   a. Under 30"..... 330 ft.
   b. 30" - 45"..... 440 ft.
   c. Over 45"..... 660 ft.

10. Pipe Junctions
    a. Crown of pipes to match at manhole or catch basin.
    b. Angle less than 90 .

E. <u>Open Channels</u>

1. Design flows to be established by A-N West.

2. Design Frequency - 100-year.

3. Time of Concentration

   a. Overland flow time.
   b. Minimum time to ditch inlet - 10 minutes.

4. Velocities - Ditch velocities greater than five feet per second will require ditch protection. Refer to HEC No. 15. The use of soil cement, as recommended by the Soils Engineer, is undesirable due to the soil textures found in this area.

   Types of Protection:

   a. Aggregate lining.
   b. Riprap.
   c. Reinforced concrete paving.

5. Rainfall Intensity - Chart 1 Appendix II-C (As developed from Precipitation-Frequency maps of Arizona and methods presented in Weather Bureau Technical Paper No. 40).

6. Capacities

Channel capacity to be computed using Manning's Equation. Gradually varied flow to be analyzed using computer program WSPG. Freeboard for improved channels to be computed as follows:

a. Subcritical Flow - 0.2 x (depth + $V^2/2g$)
b. Supercritical Flow - 0.25 x depth
c. 1.0 foot minimum

Manning's "n" values

a. Concrete lined.....0.015
b. Aggregate lined (D50 2"-4").....0.030
(D50 4"-6").....0.035
c. Erodible.....0.025

7. Minimum Desirable Slope - 0.2%.

F. **Culverts**

1. Design discharges and locations to be supplied by A-N West.

2. Design Frequency - 100-year.

3. Maximum Allowable Headwater for Design Storm

The most critical of the following:

a. 0.5 feet below top of subgrade.
b. Prevent flooding around buildings.
c. Prevent backflooding to median catch basins.

4. Manning's "n"

a. Concrete Pipe.....0.012
b. Corrugated Metal 1/2" Corrugations....0.024
c. Box Culverts.....0.015

5. Minimum Size

a. Pipe Culvert.....24"
b. Box Culvert.....4' x 6'

6. Culvert Outlet Protection

a. Desert areas with D.A. less than 0.1 mi^2 - None required.
b. Urban areas with D.A. less than 0.1 mi^2 - to be analyzed.

c. All areas with D.A. greater than 0.1 mi^2 :

Ratio of Outlet Velocity to Natural Stream Velocity	Outlet Protection
Less than 1.5	No Protection Required
1.5 to 2.0 with outlet velocity less than 10 fps	Dump rock riprap
1.5 to 2.5 with outlet velocity greater than 10 fps	Wired tied rock riprap
Greater than 2.5 or an outlet velocity greater than 15 fps	Concrete energy dissipator per HEC No. 14 or larger culvert.

Use rock density of 140 lb/ft.3 in the design of graded riprap. The dumped rock riprap shall be designed in accordance with HEC No. 15.

7. Sedimentation

   a. Drop inlets, where used, to be designed to minimize sedimentation.
   b. Minimum velocities to be established.

8. Structures

   a. Use standard ADOT culverts and headwalls.
   b. Special inlets to be considered if discharge justifies.

G. **Retention/Detention Facilities**

1. Concept to be established by A-N West.
   Refinement of A-N West's concept by consultant to be incorporated in Final Design.

APPENDIX I

D. EXTRACTS FROM COMPUTER USERS MANUAL "WATER SURFACE AND PRESSURE GRADIENT"

COMPUTER PROGRAM F0515P

W S P G

Water Surface and Pressure Gradient

Hydraulic Analysis System

USER MANUAL

April 1979

Los Angeles County Flood Control District
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W S P G

Water Surface and Pressure Gradient

Hydraulic Analysis System

USER MANUAL

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April 1979

FORWARD

This program was written for use by the Los Angeles County Flood Control District or by its Contractors on District projects.

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1.1 Introduction

This program is a hydraulic analysis system developed by the Design Systems and Standards Group of the Design Division and the Data Processing Section of the Business and Fiscal Division of the Los Angeles County Flood Control District.

2.1 Purpose

The program computes and plots uniform and nonuniform steady flow water surface profiles and pressure gradients in open channels or closed conduits with irregular or regular sections. The flow in a system may alternate between super critical, subcritical or pressure flow in any sequence. The program will also analyze natural river channels although the principle use of the program is intended for determining profiles in improved flood control systems.

3.1 General Program Description

3.2 Basic Theory

The computational procedure is based on solving Bernoulli's equation for the total energy at each section and Manning's formula for friction loss between the sections in a reach. The open channel flow procedure utilizes the standard step method. Confluences and bridge piers are analyzed using pressure and momemtum theory.

The program uses basic mathematical and hydraulic principles to calculate all such data as cross sectional area, wetted perimeter, normal depth, critical depth, pressure, and momentum.

3.3 Computational Procedure

3.3.1 Input Preparation

The channel or conduit system is initially subdivided into the following elements: system outlet, reach, transition, confluence (junction), bridge exit, bridge entrance, wall entrance (sudden contraction), wall exit (sudden expansion), and system headworks. Each element is internally assigned a number. The input data must consist of a minimum of three elements (system outlet, system headwork and any other element) and is limited to a maximum of 200 elements. A greater number of elements will require a breakup into two or more systems.

3.3.2 Flow Rates

The starting flow rate (Q) at the upstream terminus of a system is specified on a "Q" card. The flow rate (Q) is increased at the desired locations by specifying lateral inflow rates on the "JX" cards. The flow rate can be reduced by using a negative lateral Q, this reduction is intended to account for channel storage. If it is used in cases where the channel or conduit branches it should be understood no loss is computed.

3.3.3 Multiple Profiles

To obtain additional watersurface or pressure gradient profiles for different flow rates in the system, additional Q cards may be supplied. The only limitation on the number of profiles that may be run at one time is the limit on the program execution time which is set by the computer center.

3.3.4 Manning's "n"

The program uses the Manning formula for the friction loss in all types of conduits or natural channels. The program can only take one "n" value per element, however, the "n" value can change at subsequent elements. If a section has a lining composed of different roughness coefficients a composite "n" based on anticipated depth of flow should be hand computed. If an "n" value is not specified with the input data, the program uses a value of .014.

3.3.5 Water Surface Controls

Water surface controls at the downstream terminus (System Outlet S.O.) or the upstream terminus (System Headworks S.H.) are optional input values. If water-surface controls are not given the program will use critical depth controls.

3.3.6 Critical and Normal Depths

Critical depth is computed for every section for the given Q utilizing the "Specific Energy Equation".

Normal depth is computed in every reach element on a positive slope for the specified Q.

The velocity head (H_V) is computed using the mean velocity of the section. This may not be accurate in the case of a complex section such as one with shallow flow in the horizontal overbank area where velocity distribution is not uniform. If the program is to be used in this situation the user should be aware that some error may be introduced in the results. A check on the magnitude of the error can be made by the user utilizing the parabolic method to determine specific energy (see Appendix).

3.3.7 Watersurface Stages

The lower stage w.s. profile begins at the system headworks and ends at the system outlet. The computation will proceed downstream in every consecutive element as long as energy is available to maintain flow in the supercritical stage. When energy becomes expended at any point in an element, the lower stage profile will be discontinued from that point to the downstream end of that element. Then computation will resume in the next element with a critical depth control until the system outlet is analyzed.

The upper stage w.s. profile, begins at the system outlet, and ends at the headworks. Computation proceeds upstream in every element as long as the water surface at the downstream end of any two adjacent points can support the moving mass of water to flow at the critical or subcritical depth. Otherwise, computation will be discontinued from the downstream point to the upstream end of that element. Then computation will resume at the downstream end of the next element with critical depth control, provided no depth less than critical depth has been computed at that point on the lower stage profile. Then computation will proceed upstream until the system headworks is analyzed. Note that if the computed depth of flow in any open section exceeds the given section height the program will assume an additional 10-feet of vertical wall except for Channel Type 1 (see Figure 6-1) where the side slopes are extended outward until the 10-feet vertical height is reached.

The jump routine begins at the system outlet and ends at the headworks. It searches the lower stage and the upper stage profiles for points of equal energy. If a jump is encountered, it will be approximately located; and data on either the upper stage or lower stage not consistent with the greater energy theory will be deleted from every element. The final profile will be a composite of upper stage and lower stage with hydraulic jumps in between.

4.1 Data Processing System Description

All programs are written in FORTAN IV, compiled using the IBM FORTRAN H compiler executing on an IBM 370/158 using OS/VS2 MVS. The system requires the use of an input media (such as a card reader), temporary disk storage, and a printer. It is designed to run in batch mode.

Required input to the system consists of:

1. Title information.
2. Channel element definitions.
3. Cross section definition.
4. Cross section points definition.
5. Q card, of which the first is required and the subsequent Q cards are optional for change of flow rate in the system.

The entire input is thoroughly scanned for required information and range values of optional information before processing begins. If any errors are detected, processing will stop. Warnings may be issued, but they will not prevent processing.

Processing consists of three phases: Analysis of the system in the downstream direction (phase I), analysis of the system in the upstream direction (Phase II), and analysis of the downstream profile (from Phase I) and the upstream profile (from Phase II) to obtain a composite profile (Phase III). The processing was designed to continue calculating unless gross errors are encountered. Warning messages may be issued concerning tolerance levels not being reached on an iterative approximation. These may or may not effect the overall solution to the problem; however, processing continues. If gross errors are encountered, an error message will be issued and processing will stop.

Output of the system consists of three reports:

1. A listing of input with edit scanning messages.
2. A w.s. profile listing of the composite profile obtained in Phase III of processing.
3. A profile plot of watersurface and channel geometry.

5.1 Element Description

The channel, conduit or natural river system to be analyzed is subdivided into elements as stated in Section 3.3.1. The program internally numbers the elements beginning with the System Outlet (SO) as number 1. Each successive element is numbered continuing upstream to the System Headworks (SH). The maximum number of elements permissable by the program is 200.

5.1.1 Boundary Lines (Refer to Figure 5-1)

All elements are bounded on the upstream end by Section 1 and the downstream end by Section 2 except System Outlet (SO) and System Headworks (SH) which only have Section 1. The user inputs data such as base width, conduit height, etc. for Section 1 of every element. The data for Section 2 for every element is taken by the program from the upstream Section 1 of the adjacent downstream element. Elements may have considerable length between Section 1 and Section 2 as in a reach element or may have a zero length as in a bridge entrance element.

L = length of element

X = number of the element under consideration

X+1 = adjacent upstream element

X-1 = adjacent downstream element

5.1.2 System Outlet (SO) (Refer to Figure 5-2)

The system outlet is the downstream terminus of a channel. X is equal to one. X+1 can be any element except a System Headworks (SH). Note the element length is zero.

5.1.3 System Headworks (SH) (Refer to Figure 5-3)

The system headworks is the upstream terminus of a channel. Element X-1 can be any element except a system outlet. Note the element length is zero.

5.1.4 Reach (R) (Refer to Figure 5-4)

The reach element is a length of channel, drain or natural river with a constant invert slope, Q, cross section and Manning's n. A reach may have a straight or curving horizontal alignment, however, a curved reach must coincide with the beginning and end of the curve. The same applies to an angle point in the horizontal alignment, a reach must end or begin at the angle point.

In open channels (regular rectangular or trapezoidal sections) the superelevation of the watersurface is computed and printed for each point in the curve. In pressure flow, bend losses, angle point losses, and manhole losses are computed and added to the friction loss for the reach.

Element X+1 can be any element except a system outlet.
Element X-1 can be any element except a system headworks.

5.1.5 Junction Structure (JX) (Refer to Figure 5-5)

The junction structure element is used where there is lateral inflow into the system. Two different laterals can be handled by this element. Element X-1 can be any other element except a System Headworks (SH). Element X+1 can be any other element except a System Outlet (SO).

5.1.6 Transition Structure (TS) Refer to Figure 5-6

A transition structure is a gradual expansion or contraction from Section 1 to section 2. The length L may be any positive number. Element X+1 may be any element except a system outlet. (SO) Element X-1 may be any element except a system headworks (SH).

5.1.7 Bridge Entrance (BE) (Refer to Figure 5-7)

A bridge entrance is an element used where flow enters from an element without piers into an element with piers.

A bridge entrance is considered to have a zero length element even though the bridge pier nose may have a minor length.

Element X-1 may be a SO, R, JX or TS.
Element X+1 may be a R, JX, TS or SH.
It is noted that neither section 1 or 2 can be a pipe.

5.1.8 Bridge Exit (BX) (Refer to Figure 5-8)

The bridge exit is also considered to have a zero length element.

A bridge exit is an element used where flow exits from an element with piers into an element without piers.

Element X-1 may be a SO, R, JX, or TS.
Element X+1 may be a SH, R, JX, or TS.
It is noted that neither section 1 or 2 can be a pipe.

5.1.9 Wall Entrance (WE) (Refer to Figure 5-9)

This element is used when there is a sudden change in the conduit section such as a headwall or an abrupt contraction. This element is considered to have a zero length.

The user should supply the loss coefficient Kc expressed in terms of the velocity head. If left blank on the input card the program uses a value of .5 for kc. (See Hydraulic Handbooks for typical values).

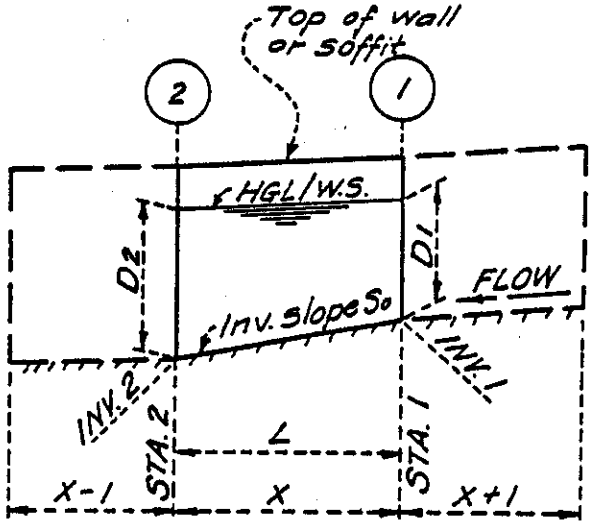
Element X-1 may be a SO, R, JX, or TS.
Element X+1 may be a SH, R, JX, or TS.
The section for element X+1 cannot have piers, however, it can be an open channel or closed conduit. The section for element X-1 can also be an open channel or closed conduit and it can be with or without piers.

5.1.10 Wall Exit (WX) (Refer to Figure 5.10)

This element is used when there is a sudden expansion from a smaller to a larger channel or conduit section. This element is considered to have a zero length.

Element X-1 may be a SO, R, JX or TS.
Element X+1 may be a SH, R, JX or TS.
The section for element X+1 may be an open channel or closed conduit with or without piers. The section for element X-1 may be an open channel or closed conduit however it cannot have piers.

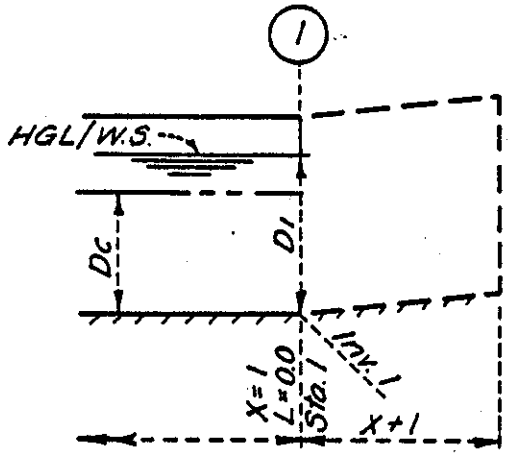
ELEMENT BOUNDARY LINES



ELEVATION

FIG. 5-1

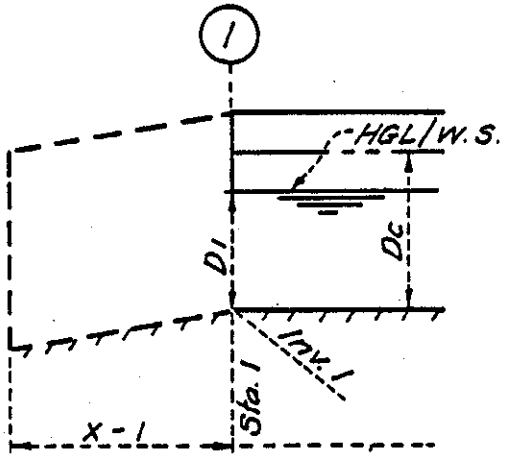
SYSTEM OUTLET



ELEVATION

FIG. 5-2

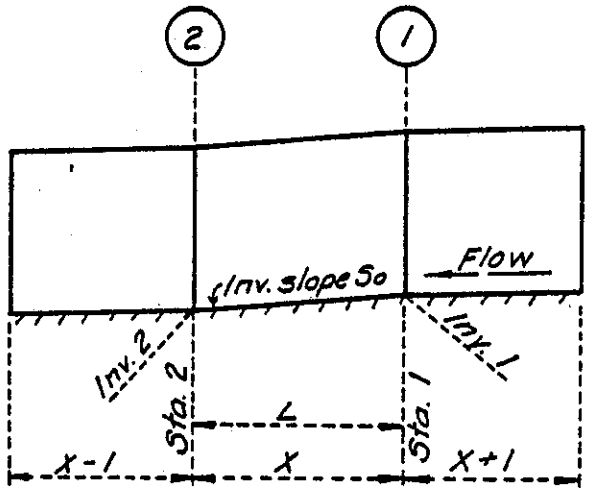
SYSTEM HEADWORKS



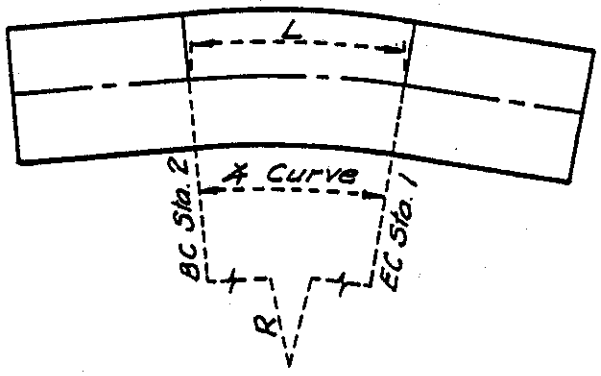
ELEVATION

FIG. 5-3

REACH

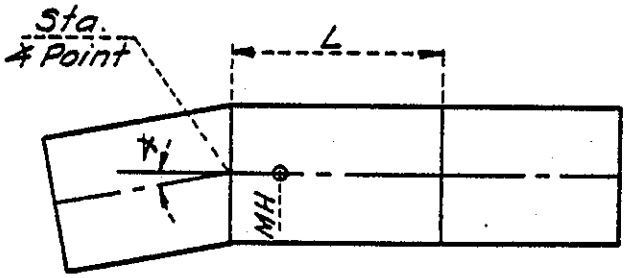


ELEVATION



PLAN A

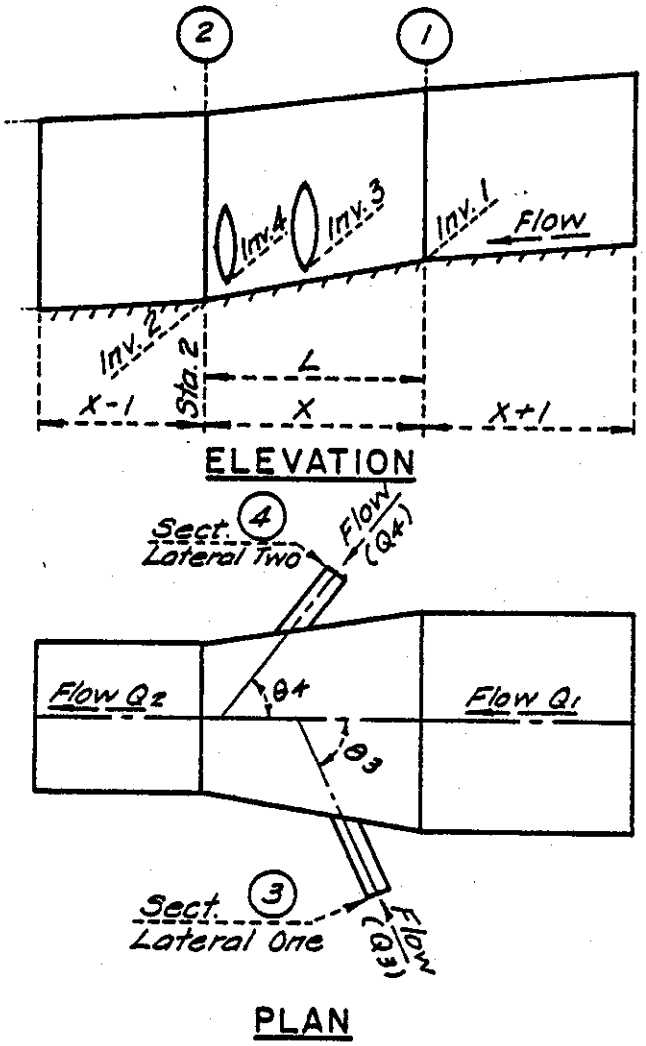
(EXAMPLE OF CURVED ALIGNMENT)



PLAN B

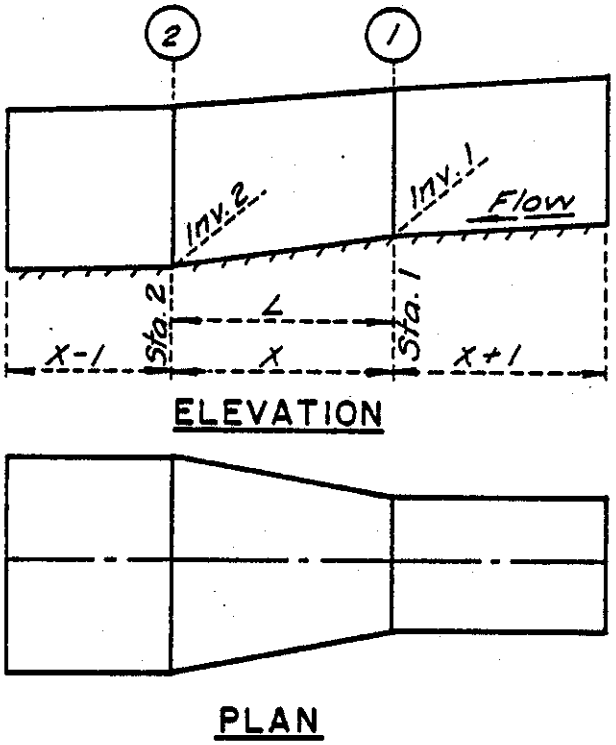
(EXAMPLE OF A STRAIGHT REACH WITH ∡ PT. AT D/S END)

FIG. 5-4



JUNCTION

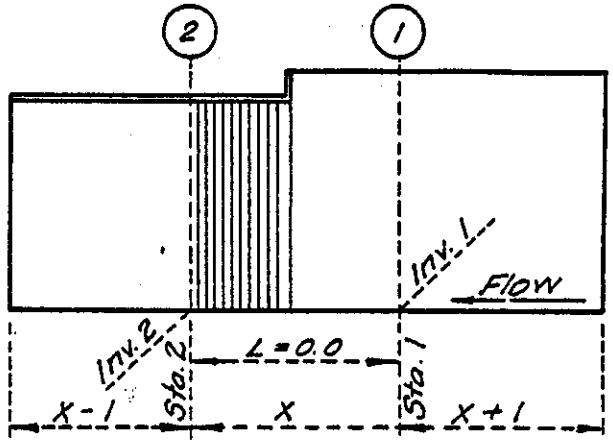
FIG. 5-5



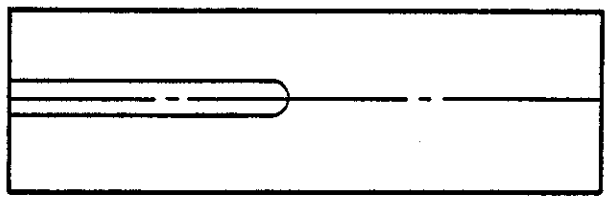
TRANSITION

FIG. 5-6

BRIDGE ENTRANCE



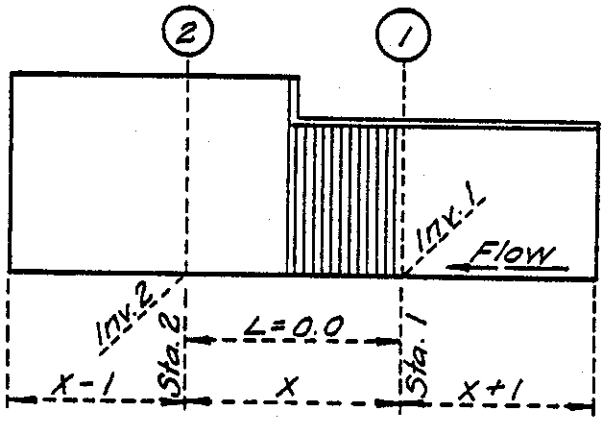
ELEVATION



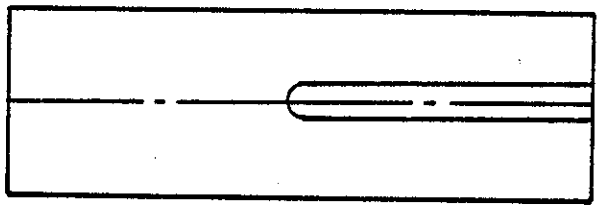
PLAN

FIG. 5-7

BRIDGE EXIT



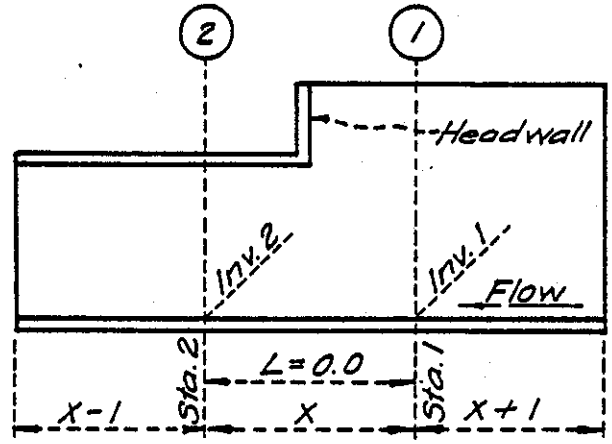
ELEVATION



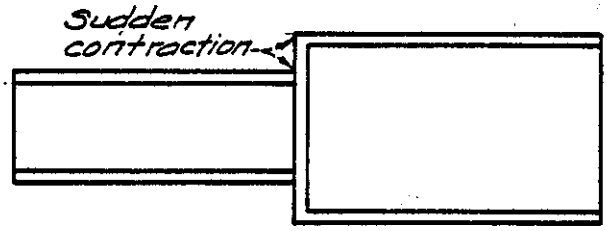
PLAN

FIG. 5-8

WALL ENTRANCE / SUDDEN CONTRACTION



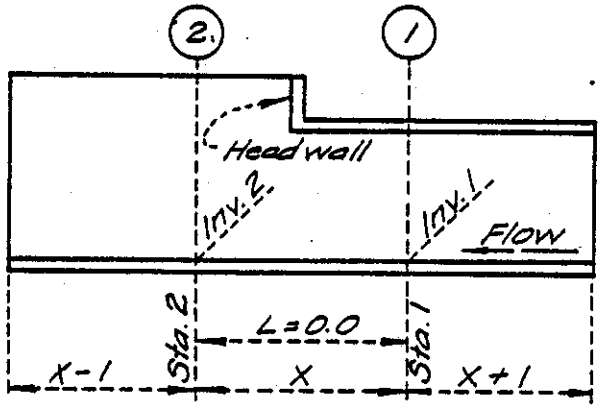
ELEVATION



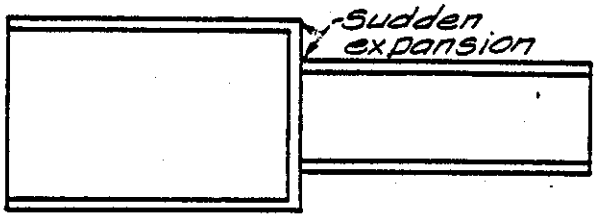
PLAN

FIG. 5-9

WALL EXIT / SUDDEN EXPANSION



ELEVATION



PLAN

FIG. 5-10

6.1 Channel and Conduit Section Description

Channels and conduits sections are classified as regular or irregular sections. The regular sections (Channel Types #1 - #4) are trapezoidal, rectangular channels, box conduits or pipes. The irregular sections (channel Types #5 and #6) can be natural river sections or irregular shaped improved sections with or without a cover. Piers or center walls can be included in any section except a pipe section.

6.1.1 Regular Channel Type Sections

The program utilizes the following regular sections:

Chan. Type # 1: Trapezoidal open top with or without piers. See Figure 6-1.

Chan. Type # 2: Rectangular open top with or without piers. See Figure 6-2.

Chan. Type # 3: Box, covered trapezoidal or covered rectangular with or without piers. See Figure 6-3.

Chan. Type # 4: Circular "pipe" one cell only. See Figure 6-4.

Note in multiple cell sections the cells may have variable width but must be of equal height and on the same invert elevation. The top elevation of all piers in both regular or irregular channels are assumed equal.

6.1.2 Irregular Sections

The program utilizes the following irregular cross sections:

Chan. Type # 5: Irregular open top with or without piers. See Figure 6-5.

Chan. Type # 6: Irregular covered top with or without piers. See figure 6-6.

6.1.3 Definitions & Restrictions for Irregular Sections

An irregular cross section (facing upstream) is defined by x and y coordinates of points i (x, y) given in a counter clockwise direction, from point i=1 to point i=n (minimum 3 points and maximum 99 points).

Point i = 1 (x, y) is where
x (1) = x min and if x (2) is also x minimum then
y (1) is greater than y (2)

LIMITATIONS

Location of x and y axis:

The center of the reference axis (x=o,y=o) must not fall on the perimeter of the cross section.

Flow Line:

A section can have only one low flow channel.

Section Shape:

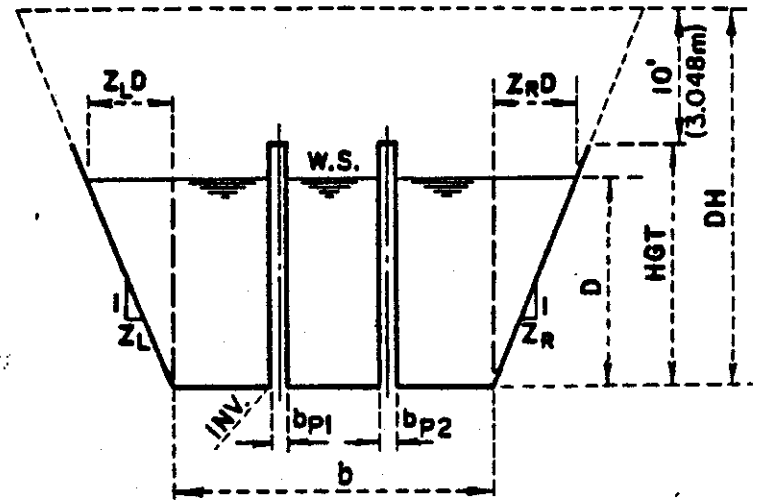
A section is allowed one minimum and maximum in the x and y directions. For example between points from x minimum to x maximum the consecutive values of x must be equal or greater. From x maximum to x minimum the consecutive values of x must be equal or smaller. The same holds in the y direction.

Piers:

The reference (x, y) axis for piers must be the same as used for the cross section. The "y" values are given from left to right.

FIG. 6-1

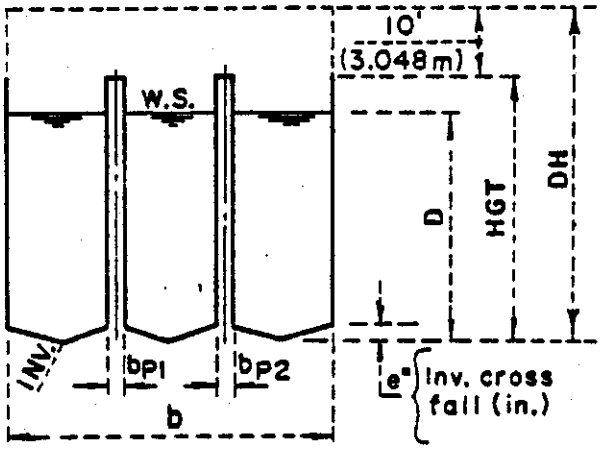
Trapezoidal section with or without piers.



CHAN TYPE 1

FIG. 6-2

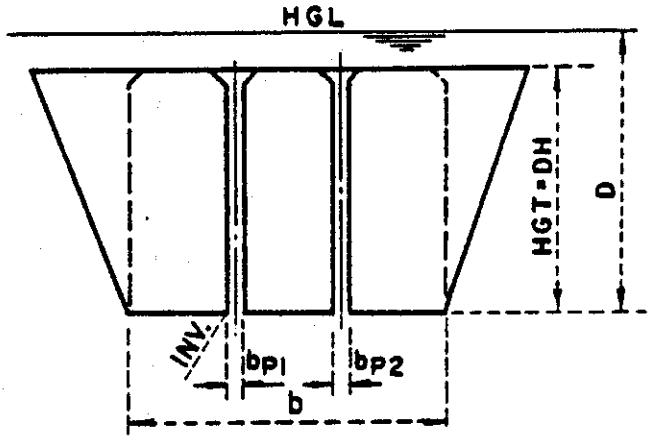
Rectangular section with or without piers.



CHAN TYPE 2

FIG. 6-3

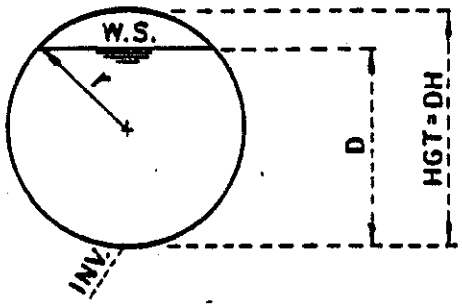
Box culvert, covered trap or rectangular section with or without piers.



CHAN TYPE 3

FIG. 6-4

Circular section (pipe) one cell only.

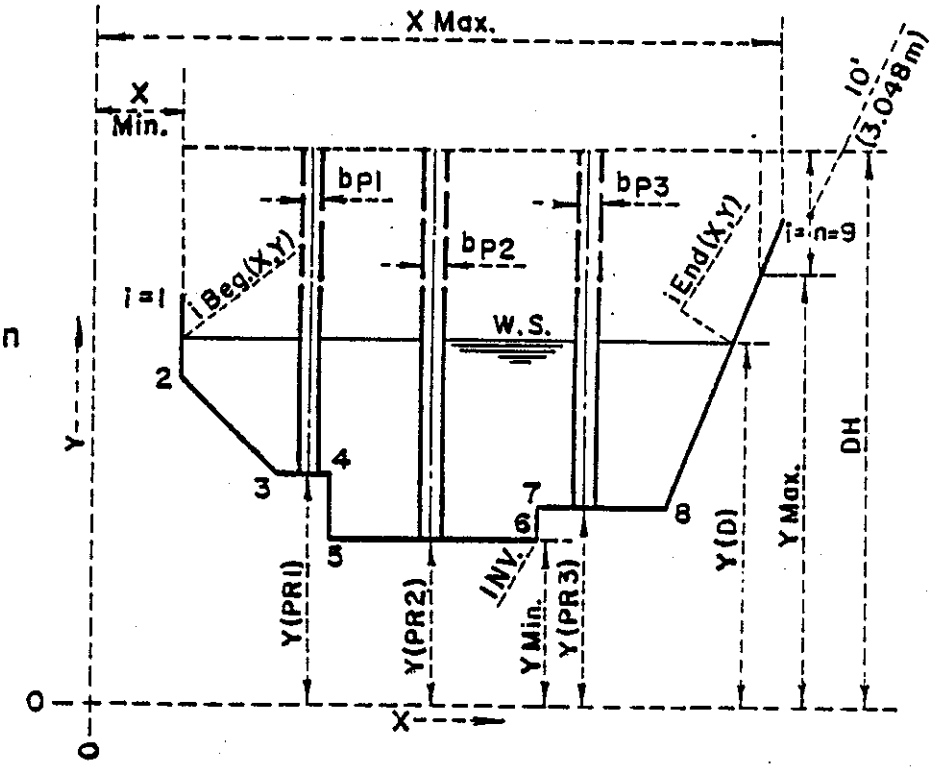


CHAN TYPE 4

IRREGULAR CHANNELS

FIG. 6-5

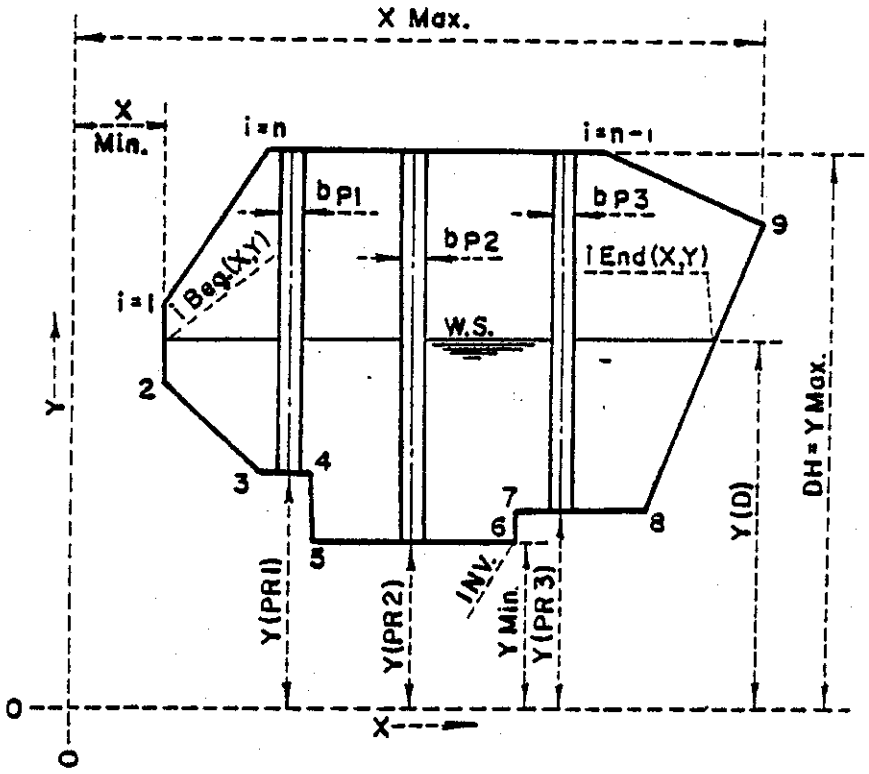
Irregular open top section with or without piers.



CHAN TYPE 5

FIG. 6-6

Irregular covered section with or without piers.



CHAN TYPE 6