CITY OF SCOTTSDALE

DESERT GREENBELT
PIMA ROAD THREE BASINS PROJECT

Pima Road Conduits
Hydraulics Memorandum

The Desert Greenbelt
SCOTTSDALE, ARIZONA

SCI Project Number: 28900051

April 1998

Stantech
Consulting

CITY OF SCOTTSDALE

DESERT GREENBELT
PIMA ROAD THREE BASINS PROJECT

Pima Road Conduits
Hydraulics Memorandum

The Desert Greenbelt

SCOTTSDALE, ARIZONA

STANTECH CONSULTING INC.
7776 Pointe Parkway W., #290
Phoenix, Arizona 85044
(602) 438-2200

SCI Project No: 28900051

April 1998

Registered Professional Engineer (Civil)
CERTIFICATE NO. 17928
GEORGE V. SABOL
Date Signed 29 Apr. 1998
ARIZONA, U.S.A.

Table of Contents

		Page
1.0	**INTRODUCTION**	**1**
1.1	General	1
1.2	Background	2
1.3	Purpose	3
2.0	**HYDROLOGY**	**4**
2.1	Basis Of Hydrology	4
2.2	Methodology	4
2.3	Design Discharge Estimates	5
3.0	**HYDRAULICS**	**5**
3.1	General	5
3.2	Parameter Estimation	6
3.2.1	Manning's n Value	6
3.2.2	Headloss Coefficients	6
3.2.3	Starting Tailwater Condition	6
3.3	Results Of Hydraulic Analyses	7
3.4	Independent Analyses By Others	7
3.5	Conclusions And Recommendations	8

LIST OF TABLES

Table 2-1: Pima Road Design Discharges

LIST OF FIGURES

Figure 1-1: General Site Map

LIST OF APPENDICES

Appendix A: Preliminary Plan and Profile Sheets for Conduits

Appendix B: Hydraulics Calculations Sheets and Tables

Appendix C: HGL Profile Plot

Appendix D: Preliminary Hydraulic Analysis Report by D.J. Brauer, PE

Appendix E: Cast-In-Place Earth Reinforced Concrete Pipe Alternative Storm Drain System by Curtiss W. Gilley, PE

1.0 Introduction

1.1 GENERAL

The Pima Road Conduits are a storm drain system that is part of the Desert Greenbelt, Pima Road Three Basins (PR3B) Project by the City of Scottsdale. The PR3B Project is a continuous system of conveyance channels and/or conduits, storm drains, lateral junctions to the conveyance systems, three detention basins, and outlet conduits from the basins. The PR3B Project extends from about one-quarter mile north of Jomax Road to the U.S. Bureau of Reclamation (USBR) detention basin at the City of Scottsdale, Tournament Players Club (TPC) Golf Course. The PR3B Project, at its outlet at the TPC, receives runoff from a total drainage area of 12.4 square miles. Figure 1-1 shows the essential elements of the PR3B Project.

The PR3B Project is to be built in two phases. Phase 1 consists of an interim sized Deer Valley Detention Basin (DVDB) and all facilities south of that basin. All facilities, except the DVDB, in the Phase 1 construction are designed for the full project (Ultimate Condition) 100-year discharges. Phase 2 of the project will include enlargement of the DVDB to its ultimate capacity, the Happy Valley Detention Basin and the remainder of the Pima Road conveyance system north of the DVDB.

This report addresses the hydraulics of the Pima Road Conduits, and those conduits extend from the Sierra Pinta Road alignment at the southwest corner of DC Ranch to the Outer Loop Basin along the north side of the Outer Loop Freeway. That basin extends from Scottsdale Road to the Union Hills Traffic Interchange (T.I.). The Pima Road Conduits are approximately 7,650 feet in length.

The Pima Road Conduits will consist of double barrel, large diameter concrete pipe for its entire length from Sierra Pinta to the Outer Loop Basin. At its upper end (Sierra Pinta) a junction box will be designed to receive inflow from the Pima Road Storm Drain (the outlet from the DVDB) and from the DC Ranch, Sierra Pinta Collector Channel. The design discharges for each of those inflows are 411 cfs from the storm drain and 2,033 cfs from the collector channel. The combined peak discharge from those two sources is 2,251 cfs. The Pima Road Storm Drain is a conduit outlet from the DVDB that also receives some lateral inflow from DC Ranch, and that storm drain is discussed in the Pima Road Storm Drain, Drainage Design Report, by Stantech Consulting, Inc., February 1998. The Sierra Pinta Collector is the major source of

discharge to the Pima Road Conduits. There are three additional lateral junctions that contribute inflows to the conduits. The first is at Downing Olson Road where the contributing flow increases the conduit peak discharge by 126 cfs. The second is at Union Hills Road where the peak discharge is increased by 415 cfs. The last lateral inflow is at the Solid Waste Transfer Station where the peak discharge is increased by 79 cfs. The last junction may be eliminated and the discharge taken directly to the Outer Loop Basin. At present, it is envisioned that junction boxes at each lateral inflow will bifurcate the flow equally into each of the conduits.

Debris deflectors and trashracks will be installed at the inlet of each lateral to the conduits to eliminate large debris. Those trashracks will also serve as safety barriers to inhibit persons and animals from being washed into the conduits during flood events.

The outlet of the conduits at the Outer Loop Basin will terminate with an appropriate energy dissipater. The conduit outlets will also be fitted with safety barriers to prohibit ingress to the conduits from its terminus.

Manholes will be installed along each conduit at about 600-foot spacing. Those manholes serve an hydraulic function as well as providing access and ventilation of the conduits for maintenance. The hydraulic function of the manholes is described in a separate report by D.J. Brauer, PE (Appendix D).

1.2 BACKGROUND

The PR3B Project was initiated to consist of open channel conveyances connecting four in-line detention basins. Those basins, beginning from the north, are the Happy Valley Detention Basin, the Deer Valley Detention Basin, the Union Hills Detention Basin, and at its southern end the existing USBR detention basin at the TPC Golf Course. The third basin (the Union Hills Detention Basin) was to be located near the Union Hills T.I. In addition, a separate drainage system (the Outer Loop Drainage) was to be constructed to the west of the Pima Road system, and another basin (the Miller Road Detention Basin) was to be constructed as part of the Outer Loop Drainage. The initial PR3B Project is described in two 10% design reports; one for the Pima Road portion and the second for the Outer Loop Drainage portion. As a result of a Value Engineering study, the project was reconfigured. The major changes to the project undertaken in Phase 1 are:

- The two separate Union Hills and Miller Road Detention Basins are eliminated and replaced by a single linear basin (the Outer Loop Basin).

- The open channel conveyance from Sierra Pinta Road south to the Outer Loop Basin is replaced with large diameter conduits.

- The separate outlets from the Union Hills and the Miller Road Detention Basins that discharged to the TPC Golf Course (one at the east near Pima Road and one at the west near Scottsdale Road) are replaced by a single outlet conduit system running south along Hayden Road.

1.3 PURPOSE

The purpose of this report is to present the basis for the design discharges to the Pima Road Conduits and to document the preliminary hydraulic design of that conduit system. The design data in this report corresponds to the conduits as shown in the preliminary design drawings that are included with this report (Appendix A). It is anticipated that the design, as it progresses, will result in changes to the design drawings contained herein. The final design of the Pima Road Conduits will be documented in a final design report. Certain project elements, such as the inflow junction as Sierra Pinta and the three other lateral inflow junctions, are not presently designed. Those will be addressed as the design progresses. In addition, the design as presented herein was independently reviewed for hydraulics by Mr. Daniel J. Brauer, PE (Appendix D), and Mr. Curtiss Gilley, PE (Appendix E). The results and conclusions by those reviewers are presented herein and their reports included as appendices. Those comments and recommendations will be considered and included, as appropriate, in design refinements.

This report is not intended to present the final hydraulic analysis nor to represent the final design of those conduits. This is a preliminary hydraulics report addressing the major hydraulic considerations for those conduits. The hydrology for the PR3B Project is presented in separate reports which are referenced elsewhere. This report does not present hydraulics of other elements of the PR3B Project, nor is it a complete or final representation of the PR3B Project design.

2.0 Hydrology

2.1 BASIS OF HYDROLOGY

Four hydrology reports relative to the PR3B Project were produced by Stantech Consulting, Inc. Those reports are:

- Watershed Hydrology and Concept Design Report, November 1997 (referred to as the Concept Hydrology Report).
- Systems Operations Design and Final Hydrology Report, November 1997 (referred to as the Systems Ops Report).
- Ultimate Conditions Design Memorandum, April 1998, and
- Interim Conditions Design Memorandum, April 1998.

The design discharges for the Pima Road Conduits are obtained from the Systems Ops Report. The watershed modeling methodology and parameter estimation are presented in the Concept Hydrology Report.

2.2 METHODOLOGY

Hydrologic modeling in the System Ops and Concept Hydrology Reports are performed using the U.S. Army Corps of Engineers' (USACOE) HEC-1 Flood Hydrograph Package computer model, version 4.0.1E, September 1990, as implemented by Dodson and Associates. Both the 100-year, 6- and 24-hour storms are modeled for the entire watershed. All drainage facilities upstream of the Outer Loop Basin are designed using 6-hour discharges. The Outer Loop Basin and its outlet conduits are all designed using 24-hour discharges. Both the 6- and 24-hour rainfalls are distributed using the hypothetical option in HEC-1. Key rainfall depth-duration-frequency statistics are obtained from the Precipitation-Frequency Atlas for Arizona (NOAA Atlas II), with point rainfall depth-duration-frequency data developed by the PREFRE program. Subbasin rainfall/runoff characteristics are modeled using kinematic wave methodology. Rainfall losses are estimated by the use of SCS curve numbers for pervious areas and an estimate of percent impervious area (RTIMP) to account for hydraulically connected rooftops and paved areas. Channel routing is accomplished using the normal depth option of the Modified Puls method.

Reservoir storage routing is performed using the level pool option of the Modified Puls method.

The HEC-1 models for both reports include insertions of modeling for DC Ranch and Grayhawk as developed by the respective engineering consultants to each project. Those models are essentially inserted without change. Some minor adjustments were made to "fit" the modeling to the PR3B system and to code in area quantities at combine locations downstream of diversion operations for proper interpolation of the index hydrographs.

2.3 DESIGN DISCHARGE ESTIMATES

The Pima Road Conduits are designed to convey the peak discharge from the 100-year, 6-hour storm as presented in the Systems Ops Report. Design discharges for the conduits are shown in Table 2-1.

TABLE 2-1
Pima Road Design Discharges

Design Segment (1)	Discharge cfs (2)	Remarks (3)
Sta. 10+00 to Sta. 22+00	2871	Outfall to Outer Loop Basin = Sta. 10+00 Inflow to conduit from Lateral 1 at Sta. 22+00
Sta. 22+00 to Sta. 32+00	2792	Inflow to conduit from Lateral 2 at Sta. 32+00
Sta. 32+00 to Sta. 44+60	2377	Inflow to conduit from Lateral 3 at Sta. 44+60
Sta. 44+60 to Sta. 86+49	2251	Inflow from Sierra Pinta Channel and Pima Road Storm Drain.
Sta.22+00	247	Lateral 1 - at Solid Waste Transfer Site
Sta. 32+00	456	Lateral 2 - at Union Hills Road
Sta. 44+60	158	Lateral 3 - at Downing Olson Road

3.0 HYDRAULICS

3.1 GENERAL

Hydraulic analysis of the Pima Road Conduits is performed using the StormCAD® program, version 1.0, by Haestad Methods. That program performs hydraulic grade line (HGL) calculations for both open channel (non-pressure) and pressure flow conditions. Hydraulic calculations are made using Manning's equation and physical data input by the user. Standard headlosses at manholes and other sources of minor losses are estimated from the tables and figures in the Drainage Design Manual for

Maricopa County, Volume II, Hydraulics, January 1996. Pressure-momentum analyses at junctions are performed using the methodology in the Orange County Flood Control District's Channel Hydraulics and Structures Design Manual, July 1972.

3.2 PARAMETER ESTIMATION

3.2.1 Manning's n Value

A Manning's n value of 0.015 is used for the analysis and is estimated based on standard values for concrete pipe (0.012), plus an adjustment to allow for degradation of the pipe, air entrainment, and sediment loads.

3.2.2 Headloss Coefficients

Headloss coefficients are estimated at the system inlet, manholes, and junction structures. All coefficients are then multiplied by the downstream (outlet) velocity head to estimate the headloss through that particular structure. Standard manholes with no other laterals are assigned a coefficient value of 0.05.

The junction structure headloss coefficients are estimated by a trial and error process. The first step is to establish the HGL at the downstream end of the conduit segment using StormCAD®. The upstream water surface at the junctions are estimated by performing a trial and error pressure-momentum analysis on the junctions using the downstream HGL information from the StormCAD® model. Once the difference in water surface is established, the coefficient for entry into the StormCAD® model is calculated. The model is then re-run to establish the water surface at the next upstream junction to be analyzed. The results of the pressure-momentum analyses (Appendix B, Table B-1) yield headloss coefficients (k_e) of 0.31 for the Union Hills junction and 0.12 for the Solid Waste Transfer Station junction. The coefficient for the Downing Olson junction (0.01) is less than a standard manhole and the coefficient for a manhole (0.05) is used in the analysis.

3.2.3 Starting Tailwater Condition

The starting elevation for the water surface at the outlet of the conduits at the Outer Loop Basin is set at the maximum water surface elevation in the basin (Elev. 1608 ft.). That tailwater condition is used because it presents the maximum pressure condition for the conduits. That starting elevation condition is conservative since it is unlikely that peak discharges from the conduits will occur simultaneously with a maximum

basin water surface elevation, however, it is a reasonable design condition since the conduits will be subjected to that pressure during design conditions.

3.3 RESULTS OF HYDRAULIC ANALYSES

The results of the hydraulic analysis are presented in Appendices B and C. Appendix B contain a connectivity schematic of the conduits with location of junctions and manholes. Tables of physical data input, hydraulic parameters and the results of the HGL calculations at node points are provided in Tables B-2 and B-3. A HGL profile drawing is provided in Appendix C. Those results indicate that the conduits, as shown, have adequate hydraulic performance for the design discharges. The hydraulic performance will be reevaluated as variations in the conduit profile are made and as the lateral inflow junctions are designed.

3.4 INDEPENDENT ANALYSES BY OTHERS

The independent analyses of the Pima Road Conduits were performed. One is by Daniel J. Brauer, PE of Future Engineering Technology Group, Inc., and that analysis primarily addresses transient flow conditions that may affect the performance of the conduits or may dictate pressures that exceed allowable criteria for cast in place (CIP) concrete pipe. The second is by Curtiss W. Gilley, PE, of Terrain Engineering, Inc., and both hydraulic and structural analyses were performed specifically in regard to the use of CIP concrete pipe for the Pima Road Conduits. Reports by Brauer and Gilley are provided in Appendices D and E, respectively.

Brauer provides a hydraulic analyses which addresses nonuniform and unsteady flow conditions for the conduits. His analysis of hydraulic jump formation leads to a recommendation to change the slopes of the conduits at two locations. That recommendation will be reviewed and considered as the design is advanced. His analysis of unsteady flow results in two significant findings: First, assuming a 25 percent (flow area) blockage in the conduits only results in a 0.5- to 1.6-foot surge pressure over the steady flow pressures, and second, the use of 5-foot diameter manholes to relieve potential surge pressures. Those manholes will be located such that the rim elevation differential between adjacent manholes does not exceed more than 15 feet in elevation. Those grated manholes also serve as air vents for air inlet and exhaust thus mitigating air backwash pressures.

Certain comments and recommendations by Brauer, such as the large air vents at station 10+50, 22+00 and 28+00 are in regions of the conduits that will be subjected

to higher static pressures due to backwater from the Outer Loop Basin. That lower section of the conduits will need to be reinforced concrete pipe (RCP) and the large air vents will not be needed.

Gilley provides a traditional hydraulic analysis and that coupled with Gilley's experience with the design and construction of CIP concrete pipe leads to assurances that CIP concrete pipe can be satisfactorily used where pressures do not exceed about 15 feet. His recommendations for design improvements will be considered as the design in refined. It is noted that his comment about the availability of 114 inch CIP concrete pipe appears to be incorrect based on recent conversations with Mr. Gordon Bluth of BluCor Contracting (this was confirmed in subsequent discussions with Gilley), and 114 inch CIP equipment is available.

Gilley also provided a structural analysis of the use of CIP concrete pipe. Based on available geotechnical data for the area, CIP concrete pipe is a suitable alternative for reinforced concrete pipe.

3.5 CONCLUSIONS AND RECOMMENDATIONS

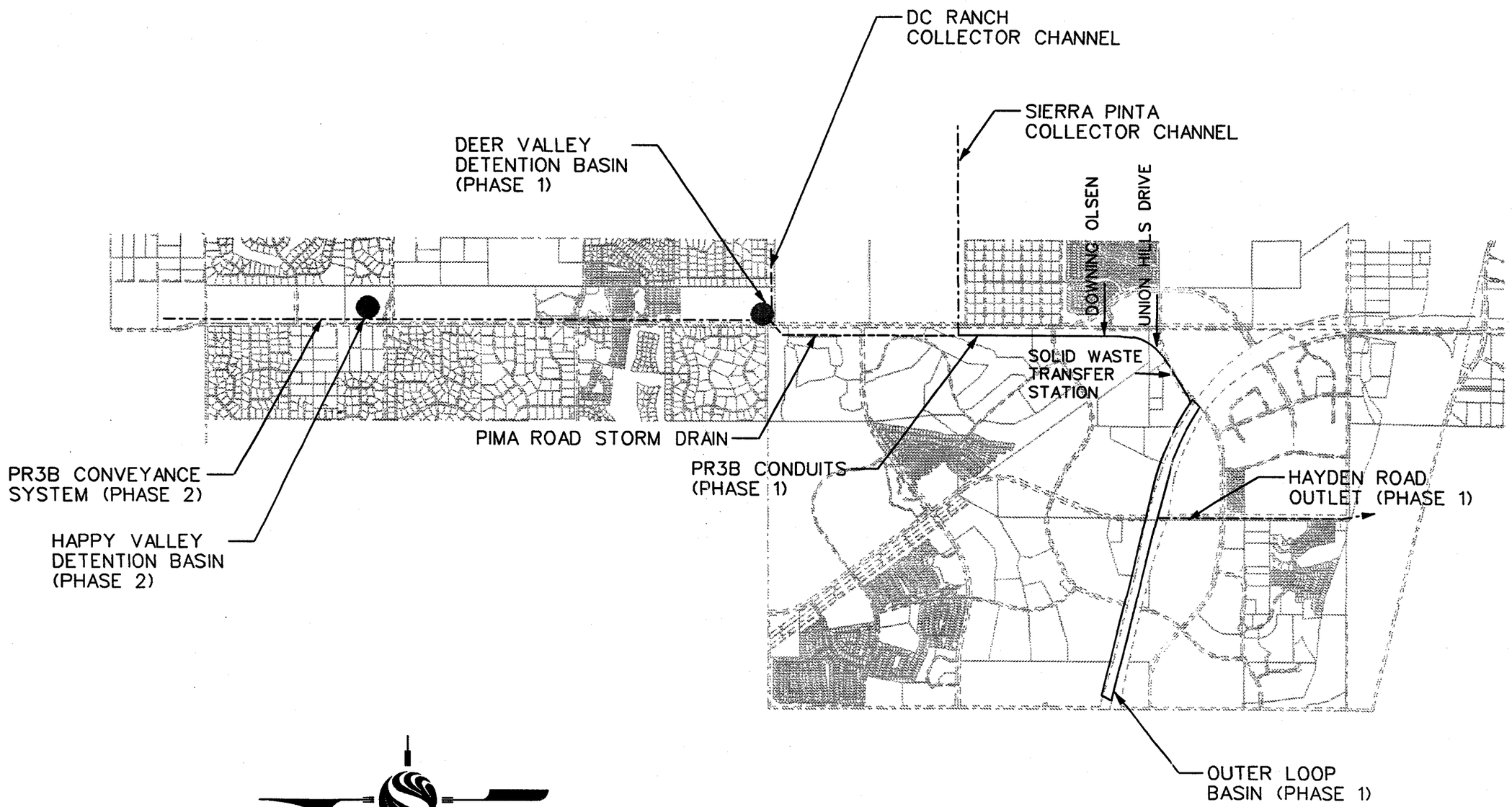
Hydraulic analysis are presented by Stantech, and supported by independent analyses by two other engineering firms, that demonstrate that the conduits as shown in the preliminary design drawings (Appendix A) will convey the design discharges. Structural analyses by Gilley indicate that the local soils are appropriate for the use of CIP concrete pipe.

Recommendations are made by Brauer to incorporate grated manholes as pressure relief and air vents to the conduits. Those manholes are features to mitigate surge pressures that could be caused due to partial flow blockage in the conduits or other unsteady flow phenomena. Such pressure relief facilities are considered necessary for the use of CIP concrete pipe. The use of those 5-foot diameter manholes are also dictated based on maintenance access and ventilation considerations.

The design of the conduits will progress including the design of the lateral inflow structures. Refinements to the hydraulic analyses will be made to reflect design changes and the recommendations presented herein.

Figure 1-1

General Site Map



0 3000 6000 9000

SCALE FEET

HORIZ. 1"= 3000'

Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

SCALE	1"=3000'
JOB No.	28900051
SHEET No.	1 OF 1

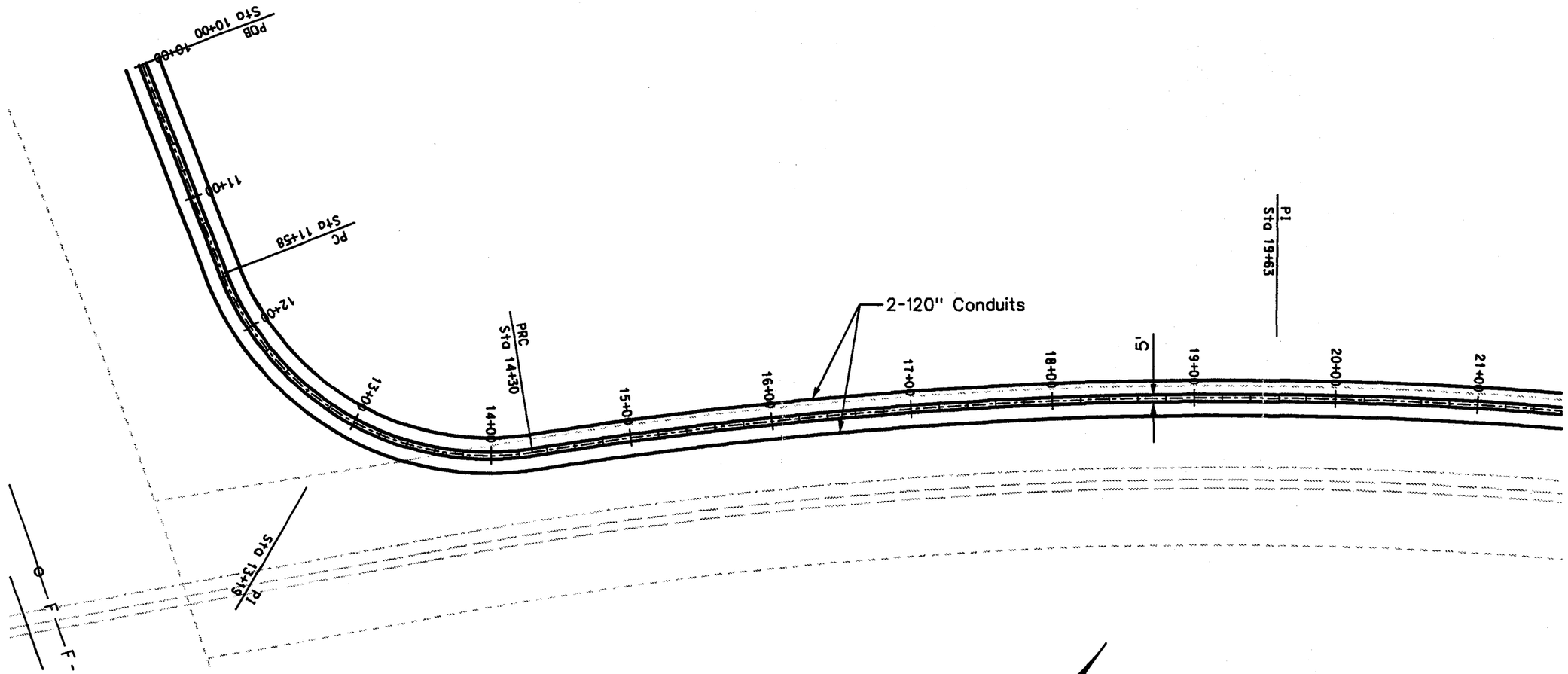
PROJECT
PIMA ROAD THREE BASINS PROJECT
PIMA ROAD CONDUITS
HYDRAULICS MEMORANDUM

SUBJECT
FIGURE 1-1
GENERAL SITE MAP

The Desert Greenbelt

Appendix A

Preliminary Plat and Profile Sheets for Conduits

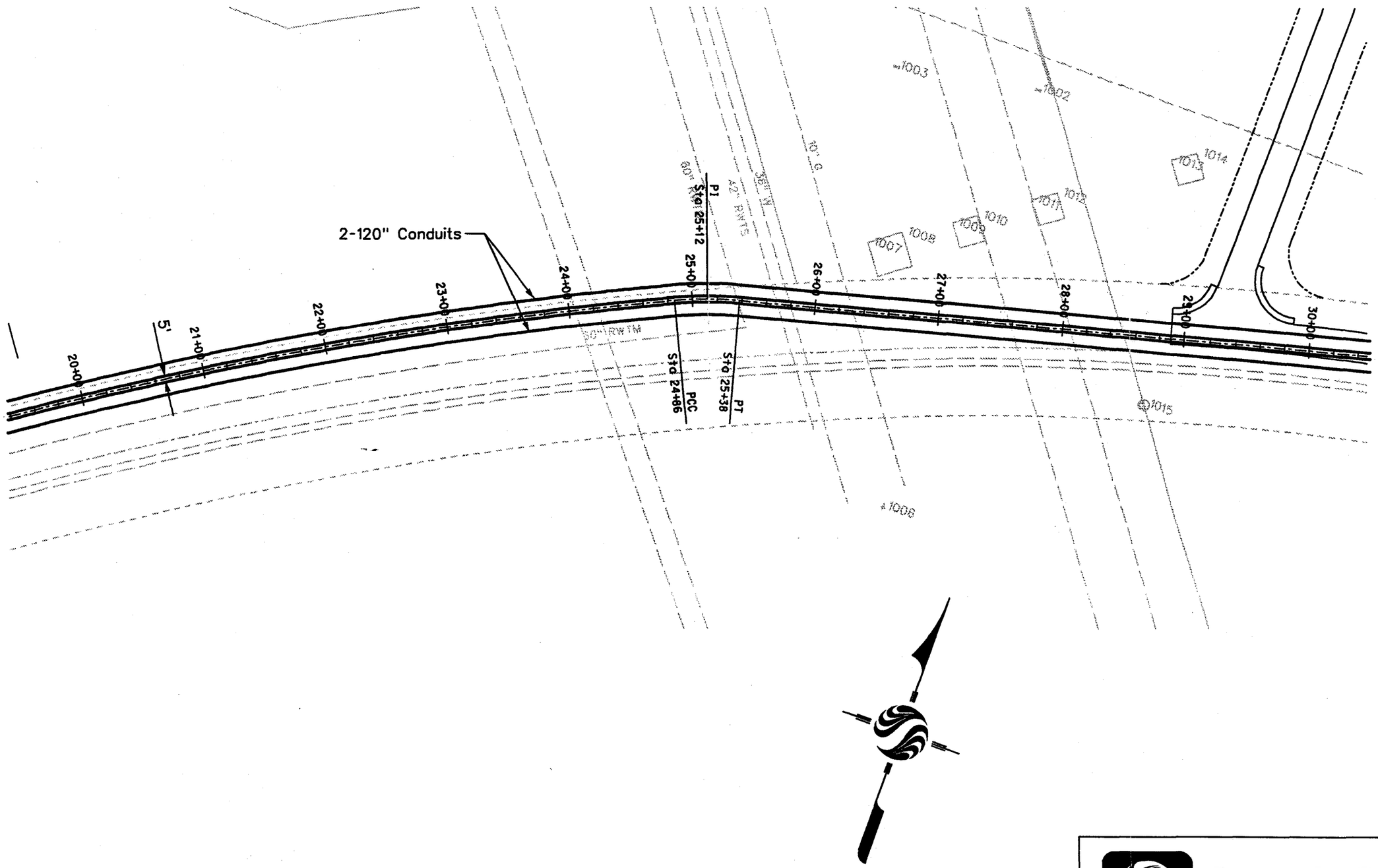


0 80 160 240

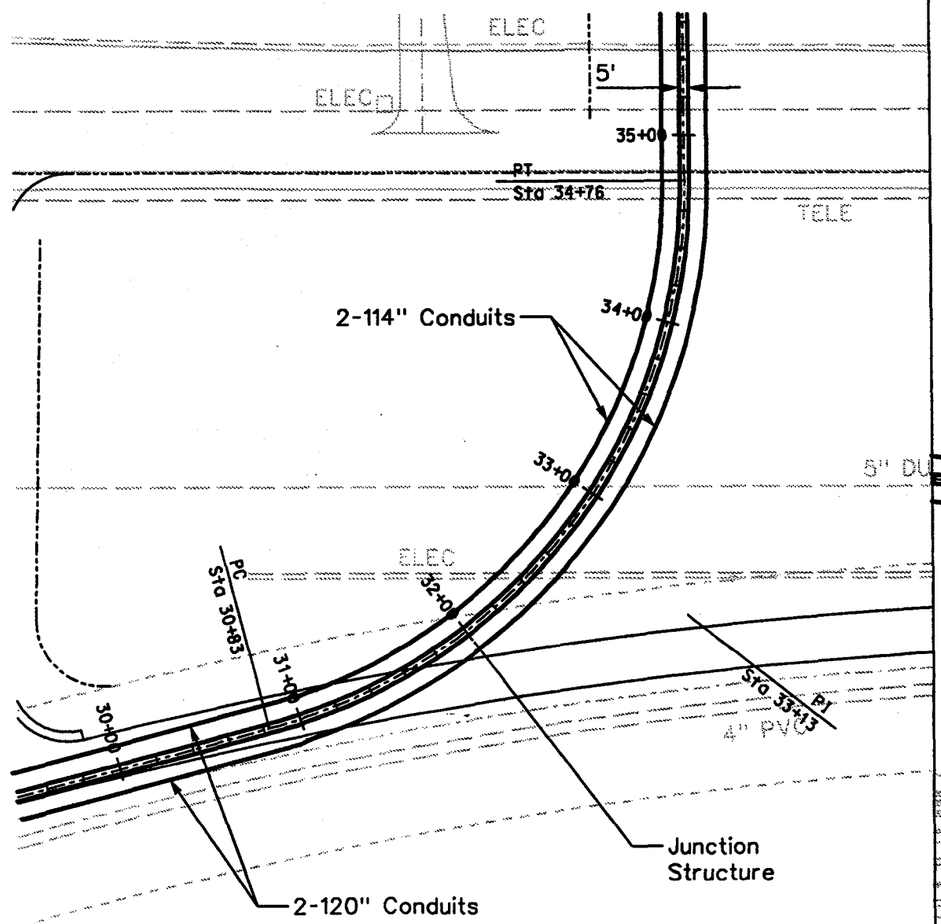
SCALE FEET

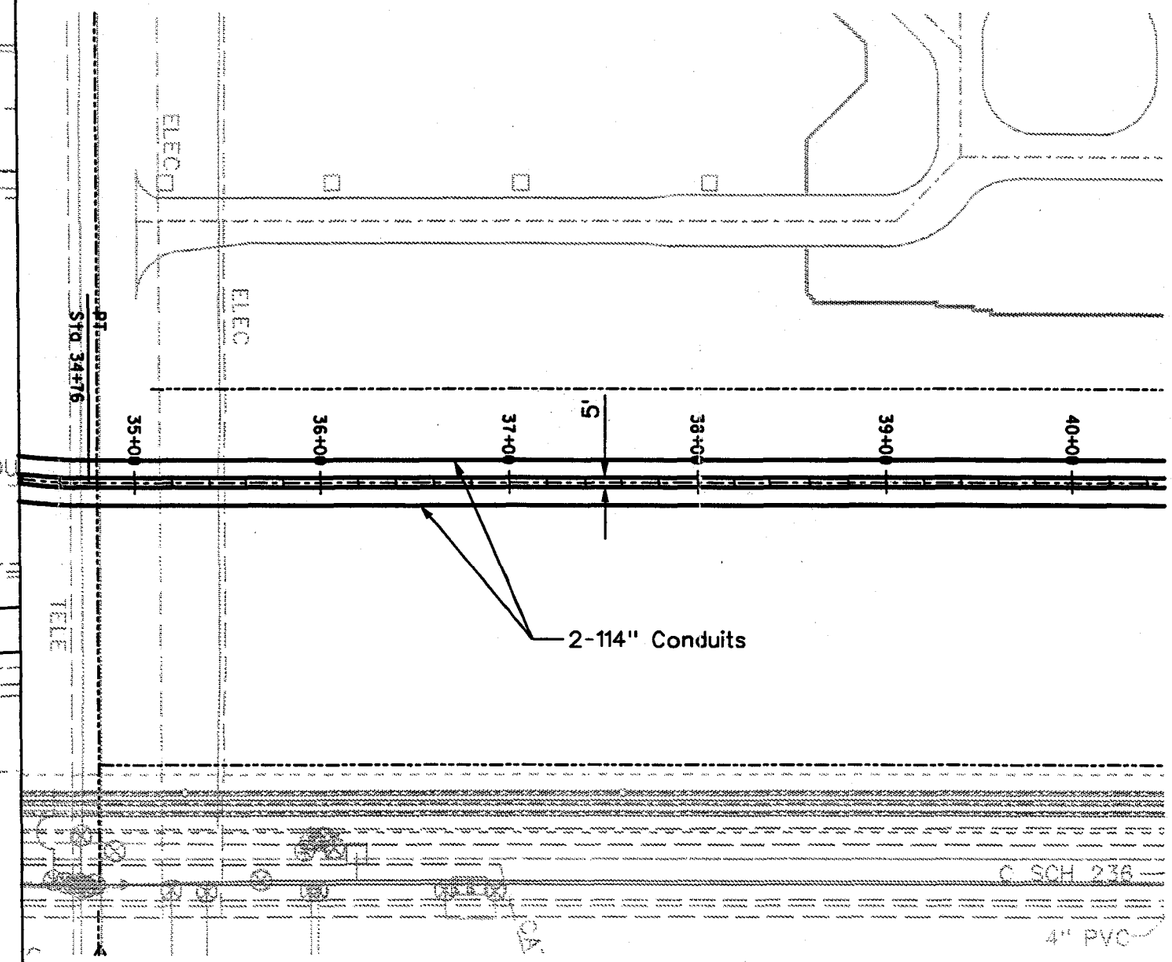
HORIZ. 1"= 80'

Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562



Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

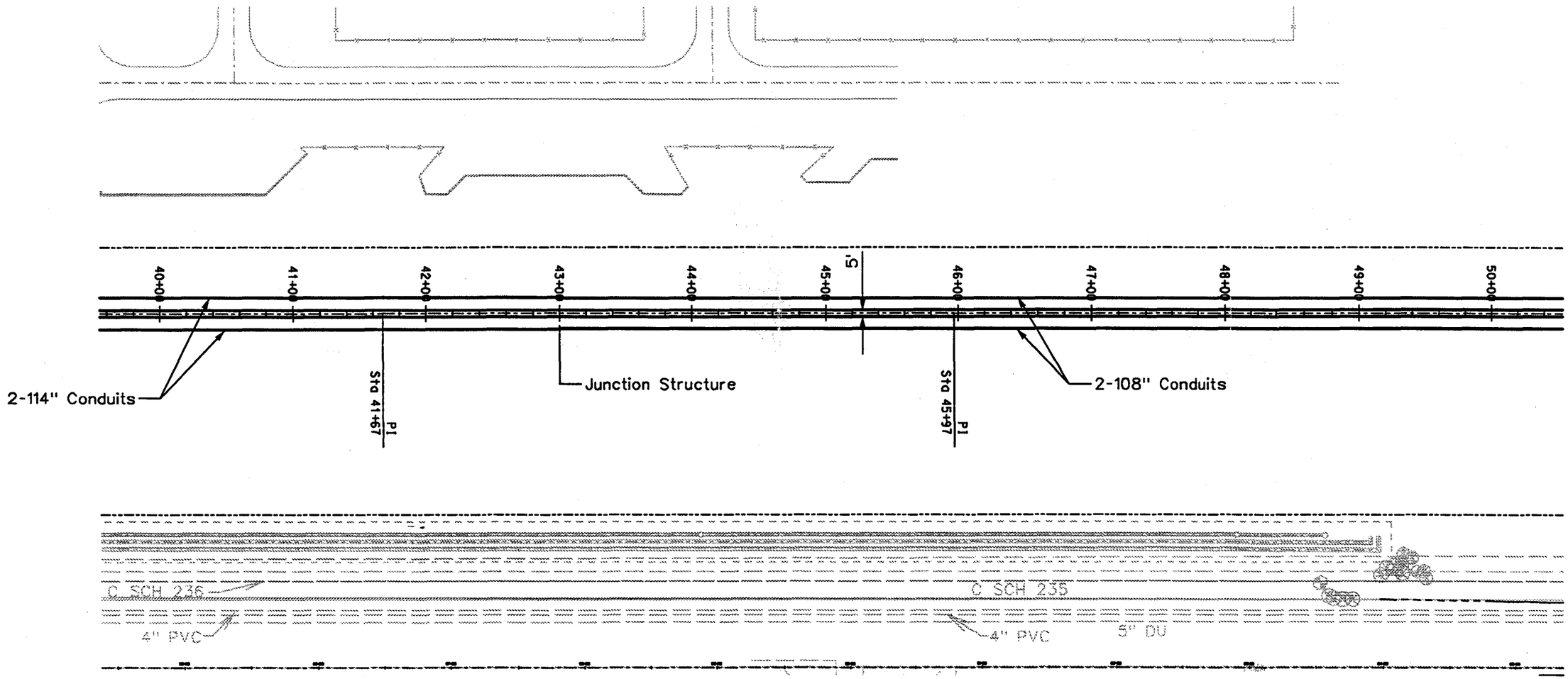


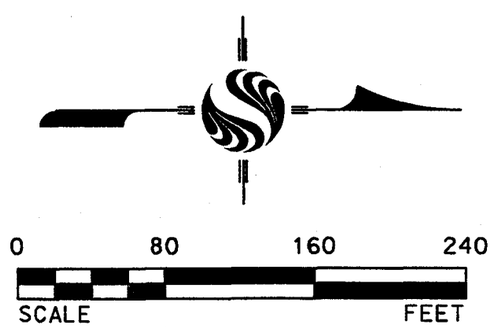


0 80 160 240
SCALE FEET
HORIZ. 1"= 80'

0 80 160 240
SCALE FEET
HORIZ. 1"= 80'

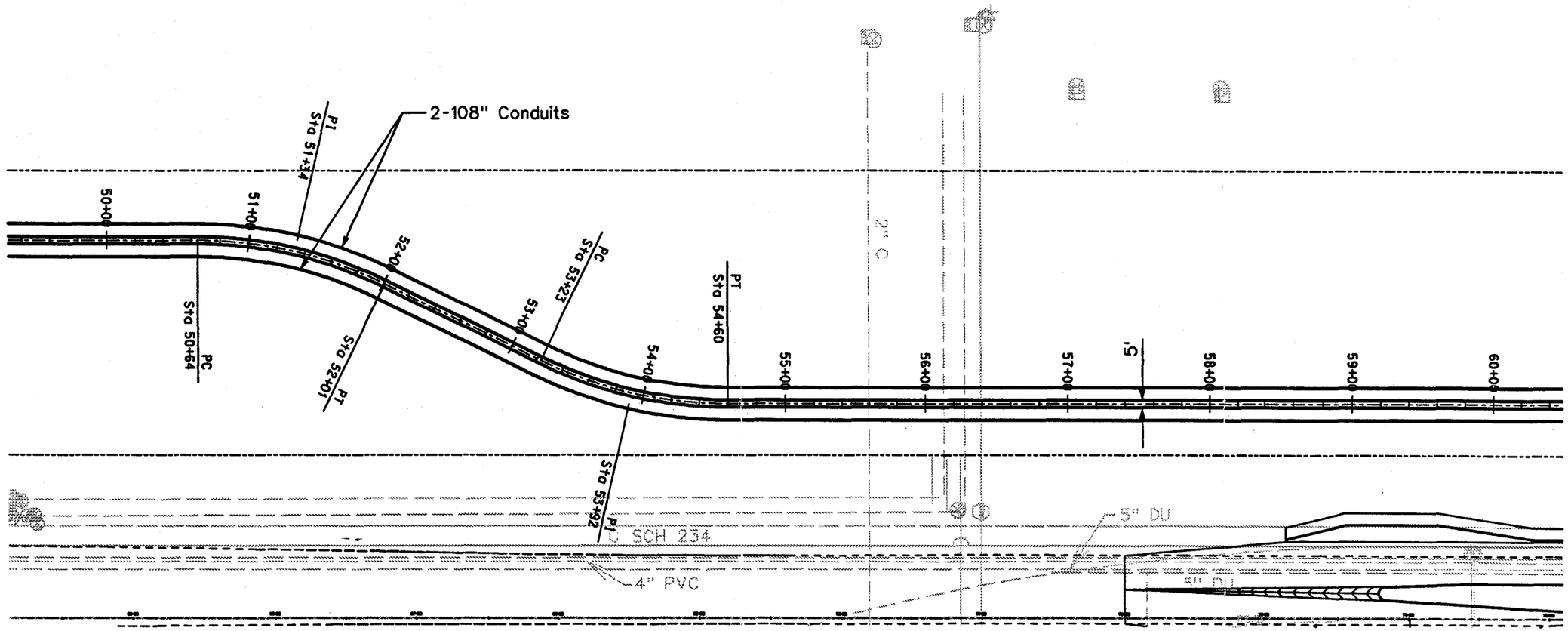
Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

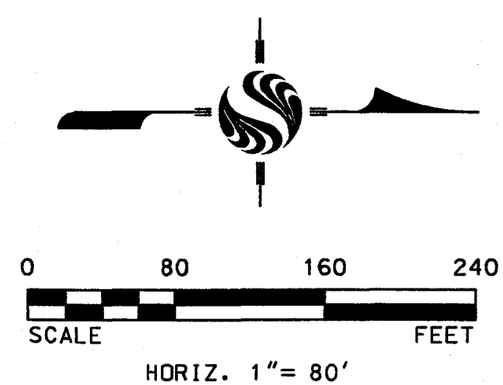




HORIZ. 1"= 80'

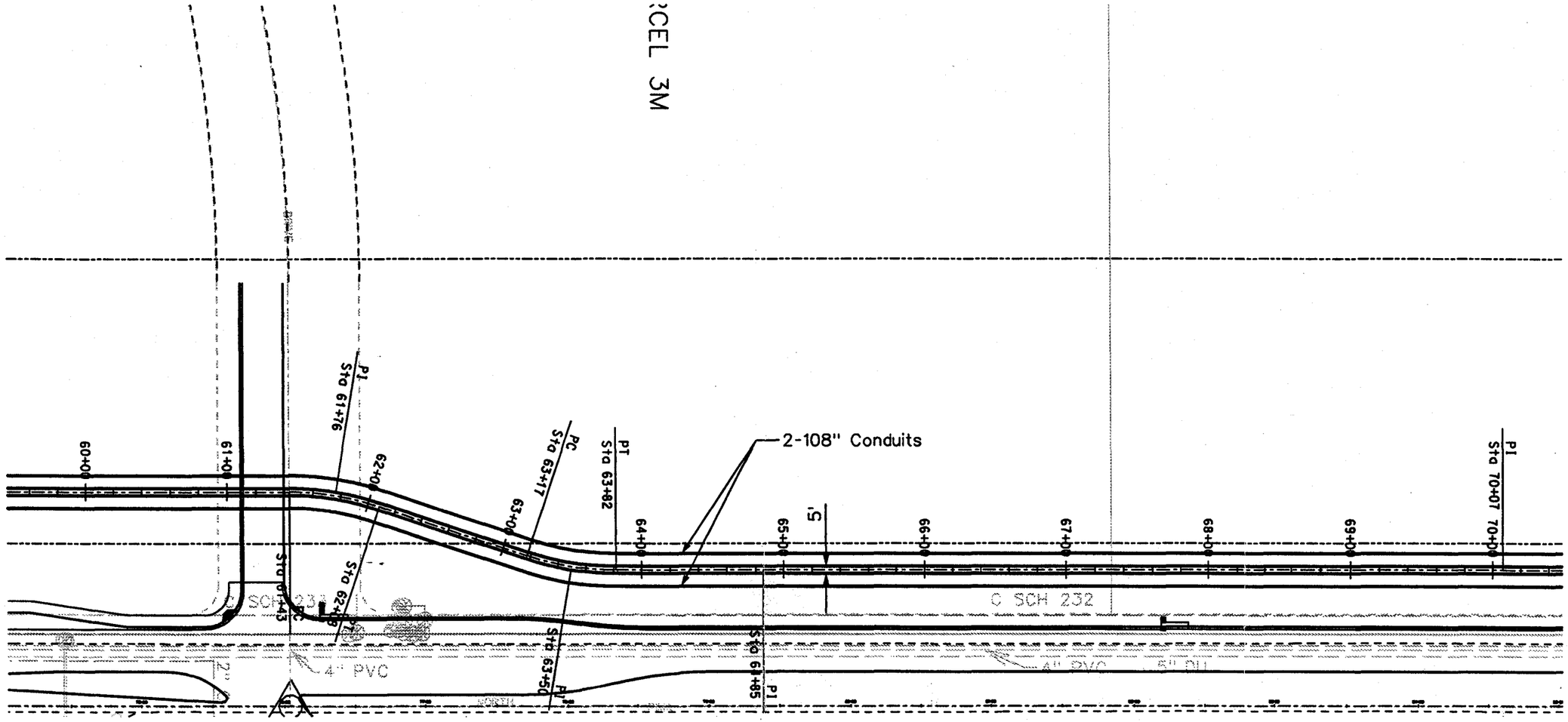
Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562





Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

:CEL 3M



0 80 160 240

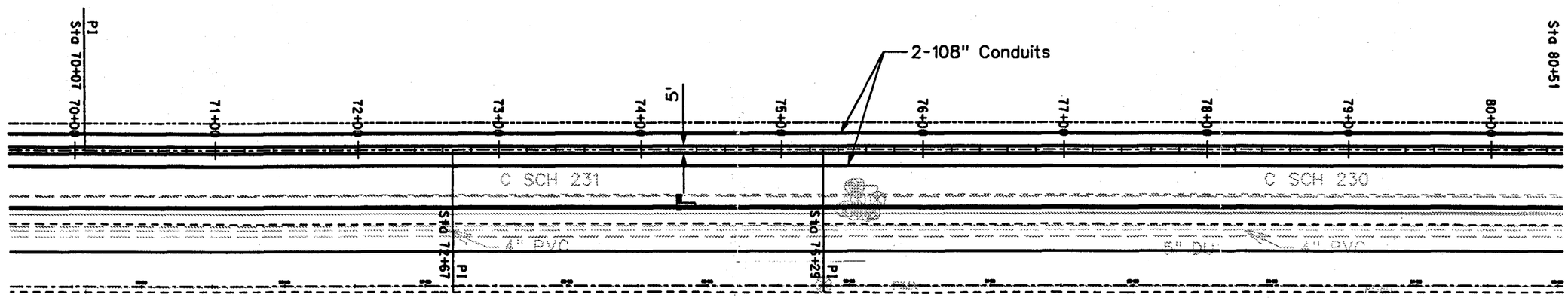
SCALE FEET

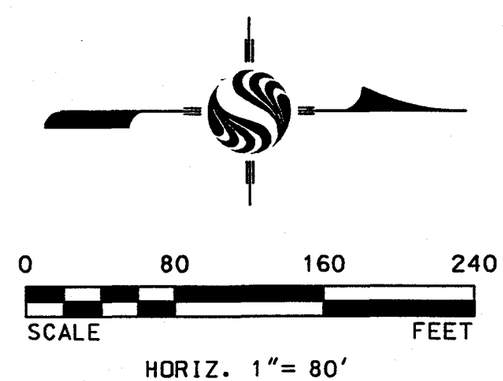
HORIZ. 1"= 80'

Stantech Consulting

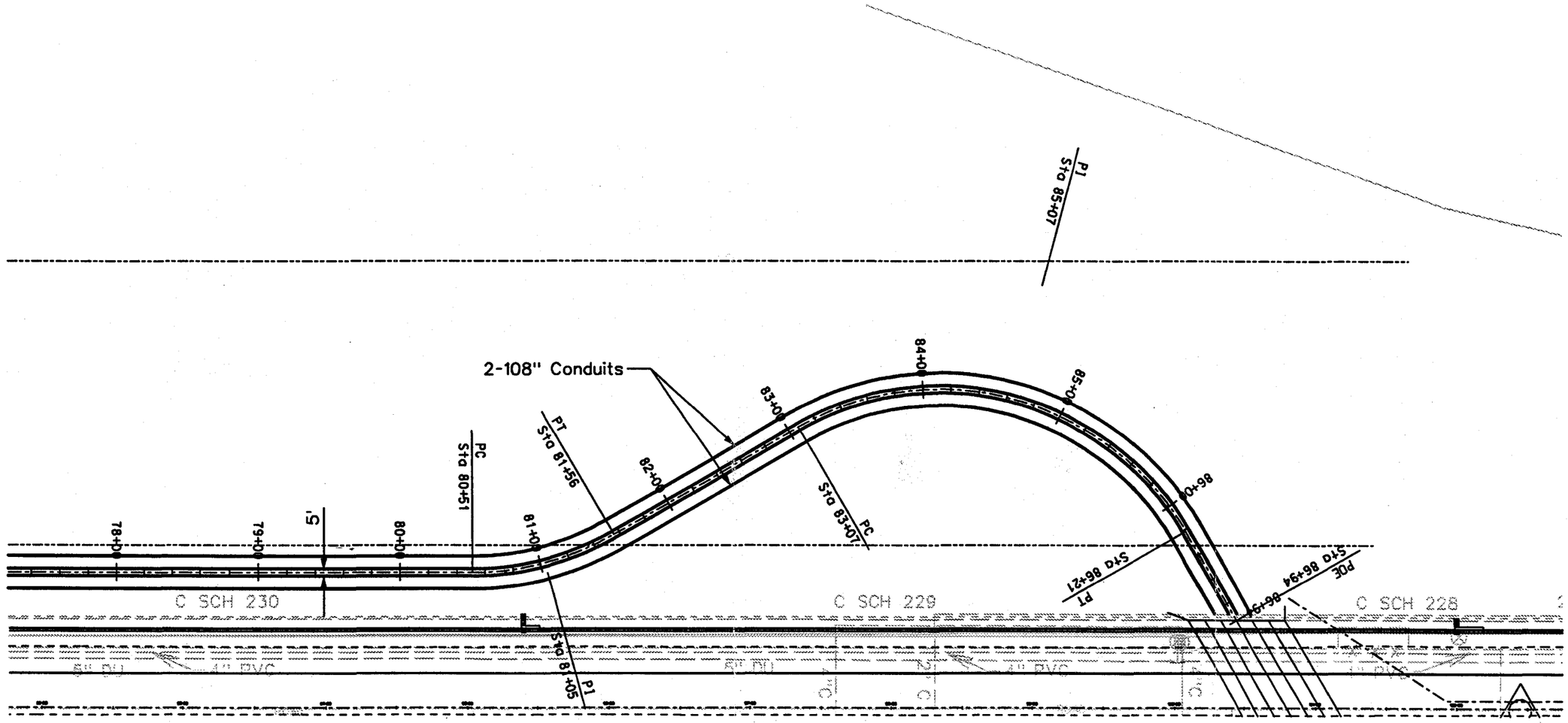
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044

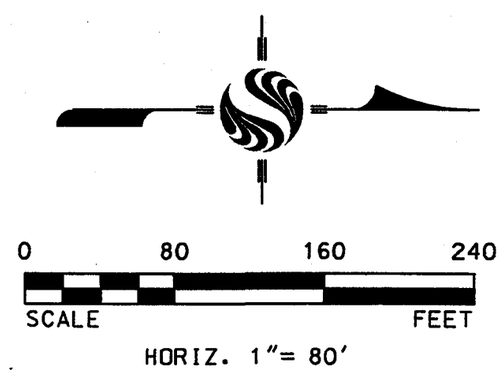
Phone: (602) 438-2200
Fax: (602) 431-9562





Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

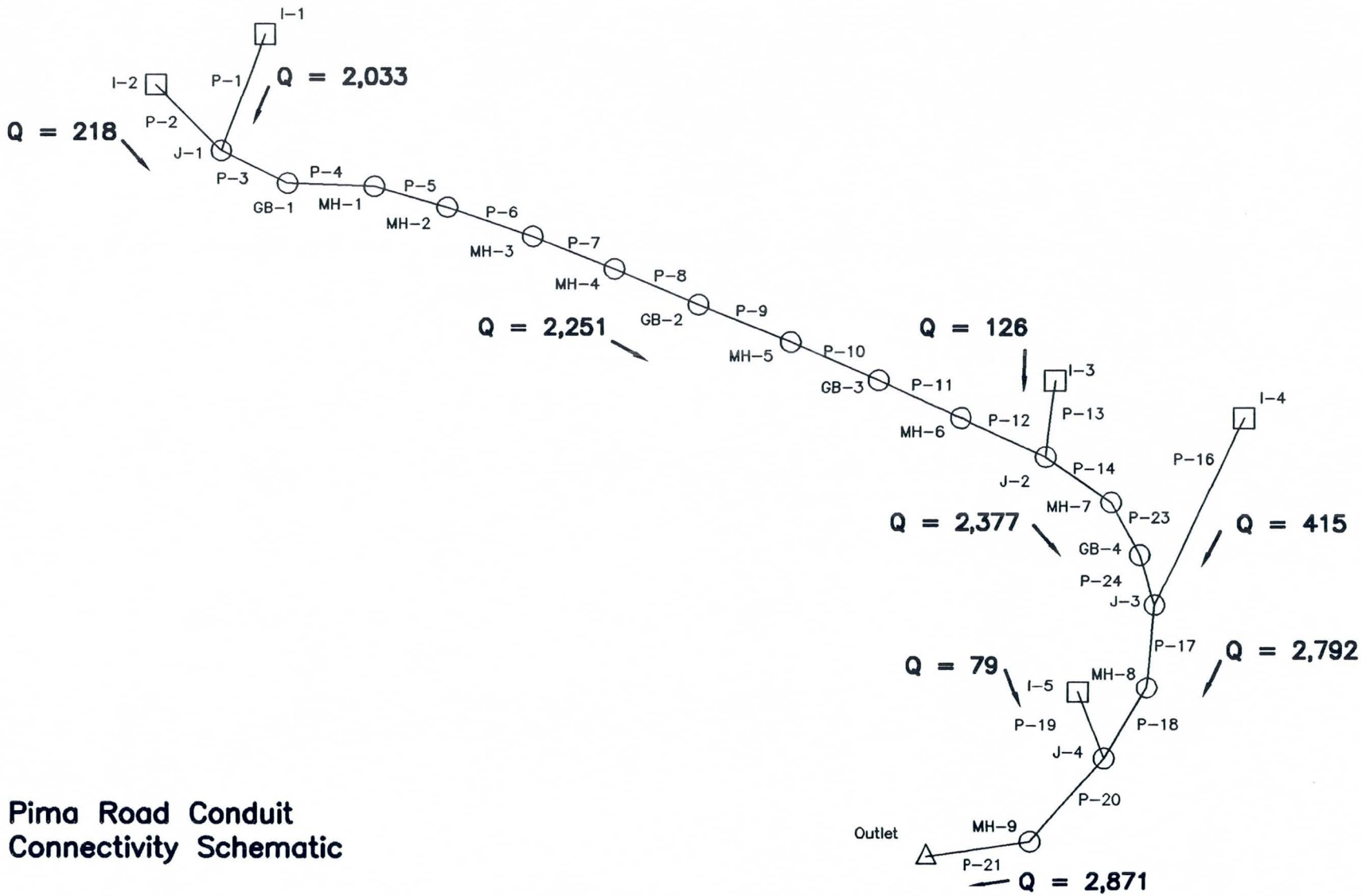




Stantech Consulting
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044
Phone: (602) 438-2200
Fax: (602) 431-9562

Appendix B

Hydraulics Calculations Sheets and Tables



Pima Road Conduit
Connectivity Schematic

Table B-1
Estimate Junction Losses
for level inverts

1) Use proceedures outlined in "Design Manual Channel Hydraulics and Structures" , Orange County Flood Control District, July 1972
2) $P_2+M_2 = P_1+M_1+M_3\text{Cos } 0 + P_l+P_w-P_f$

I.D.	Q_1 (cfs)	d_1 (ft)	Q_2 (cfs)	d_2 (ft)	d_3 (ft)	D_1 (ft)	D_2 (ft)	M_1	M_2	0 (Degrees)	O (Radians)	M_3COS0	P_1 (ft)	P_2 (ft)	P_l (ft)	P_w (ft)	S_1	S_2	L (ft)	P_f (ft)
Union Hills	1187	9.5	1392	10	5.5	15.97	14.46	619.5	768.9	30	0.52359	47.74	793.9	741.7	0.00	60.5	0.0090	0.0094	16	11.00
Solid Waste	1392	10	1431	10	4.5	20.74	20.12	768.9	812.6	30	0.52359	2.58	1234.0	1185.4	0.00	0.0	0.0094	0.0100	10	7.60
Downing Olson	1125	9	1187	9.5	5	8.3	8.26	642.2	669.7	30	0.52359	5.28	241.2	251.9	0.00	43.4	0.0108	0.0090	10	6.66

I.D.	P_2+M_2	$P_1+M_1+M_3\text{Cos } 0 + P_l+P_w-P_f$	Delta Y	$V^2_1/2g$	$V^2_2/2g$	hf	ke
Union Hills	1510.6	1510.7	1.51	4.35	4.88	0.987	0.310
Solid Waste	1998.0	1997.9	0.62	4.88	5.16	0.343	0.120
Downing Olson	921.6	925.3	0.04	4.86	4.35	0.541	0.009

D1/d1	0.92	k1 =	0.0411	c1 =	0.3308
D2/d2	0.87	k2 =	0.0429	c2 =	0.2938

Table B-2
Pima Road Conduit Pipe Report
Sierra Pinta To Outer Loop Basin

Pipe	Upstream Node	Downstream Node	Discharge (cfs)	Length (ft)	Constructed Slope (ft/ft)	Section Shape	Section Size	Roughness	Upstream Ground Elevation (ft)	Upstream Invert Elevation (ft)	Upstream HGL (ft)	Downstream Ground Elevation (ft)	Downstream Invert Elevation (ft)	Downstream HGL (ft)
P-19	I-5	J-4	79	70	0.155714	Circular	54 inch	0.015	1,623.00	1,612.00	1,621.07	1,622.80	1,601.10	1,620.92
P-13	I-3	J-2	126	130	0.002692	Circular	60 inch	0.015	1,658.50	1,645.50	1,651.83	1,656.60	1,645.15	1,651.42
P-2	I-2	J-1	218	74.65	0.077294	Circular	66 inch	0.015	1,748.90	1,737.02	1,743.43	1,745.00	1,731.25	1,743.01
P-1	I-1	J-1	2,033.00	180	0.005	Box	10 x 4 ft	0.015	1,746.00	1,740.00	1,743.29	1,745.00	1,739.10	1,743.01
P-3	J-1	GB-1	2,251.00	448	0.025223	Circular	108 inch	0.015	1,745.00	1,729.50	1,737.56	1,731.50	1,718.20	1,726.26
P-4	GB-1	MH-1	2,251.00	212	0.018868	Circular	108 inch	0.015	1,731.50	1,718.20	1,726.26	1,730.40	1,714.20	1,722.53
P-5	MH-1	MH-2	2,251.00	660	0.018485	Circular	108 inch	0.015	1,730.40	1,714.20	1,722.26	1,716.20	1,702.00	1,710.33
P-6	MH-2	MH-3	2,251.00	660	0.021212	Circular	108 inch	0.015	1,716.20	1,702.00	1,710.06	1,702.10	1,688.00	1,696.33
P-7	MH-3	Mh-4	2,251.00	660	0.020303	Circular	108 inch	0.015	1,702.10	1,688.00	1,696.06	1,688.20	1,674.60	1,682.93
P-8	Mh-4	GB-2	2,251.00	424	0.016509	Circular	108 inch	0.015	1,688.20	1,674.60	1,682.66	1,680.00	1,667.60	1,675.66
P-9	GB-2	MH-5	2,251.00	236	0.032203	Circular	108 inch	0.015	1,680.00	1,667.60	1,675.66	1,674.00	1,660.00	1,668.33
P-10	MH-5	GB-3	2,251.00	484	0.010537	Circular	108 inch	0.015	1,674.00	1,660.00	1,668.06	1,665.00	1,654.90	1,662.96
P-11	GB-3	MH-6	2,251.00	176	0.039205	Circular	108 inch	0.015	1,665.00	1,654.90	1,662.96	1,661.40	1,648.00	1,656.33
P-12	MH-6	J-2	2,251.00	344	0.014826	Circular	108 inch	0.015	1,661.40	1,648.00	1,656.06	1,656.60	1,642.90	1,651.42
P-14	J-2	MH-7	2,377.00	660	0.018485	Circular	114 inch	0.015	1,656.60	1,642.90	1,651.16	1,643.60	1,630.70	1,639.22
P-23	MH-7	GB-4	2,377.00	360	0.019167	Circular	114 inch	0.015	1,643.60	1,630.70	1,638.96	1,637.40	1,623.80	1,633.26
P-24	GB-4	J-3	2,377.00	120	0.08125	Circular	114 inch	0.015	1,637.40	1,623.80	1,633.26	1,635.10	1,614.05	1,632.18
P-16	I-4	J-3	415	428	0.008645	Circular	66 inch	0.015	1,638.50	1,620.00	1,634.35	1,635.10	1,616.30	1,632.18
P-17	J-3	MH-8	2,792.00	580	0.026121	Circular	120 inch	0.015	1,635.10	1,614.05	1,630.66	1,629.70	1,598.90	1,625.15
P-18	MH-8	J-4	2,792.00	420	0.001905	Circular	120 inch	0.015	1,629.70	1,598.90	1,624.91	1,622.80	1,598.10	1,620.92
P-20	J-4	MH-9	2,871.00	660	0.001667	Circular	120 inch	0.015	1,622.80	1,598.10	1,620.30	1,614.50	1,597.00	1,613.68
P-21	MH-9	Outlet	2,871.00	540	0.001852	Circular	120 inch	0.015	1,614.50	1,597.00	1,613.42	1,611.50	1,596.00	1,608.00

Table B-3

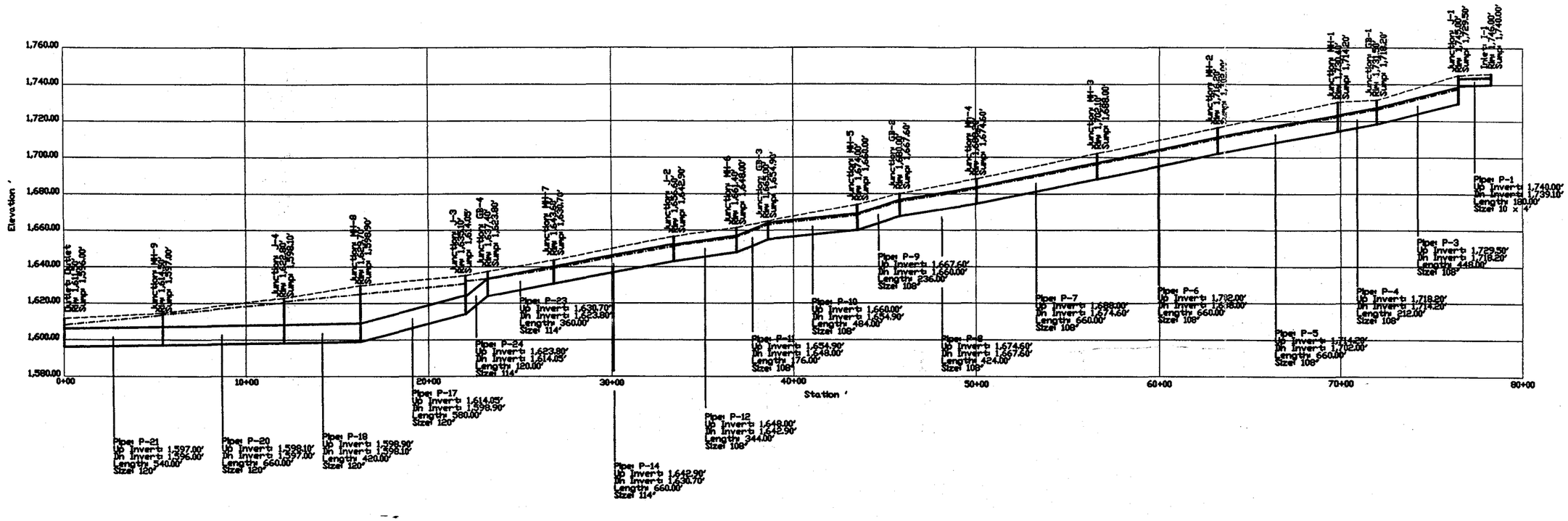
Pima Road Conduit Node Report
Sierra Pinta to Outerloop Basin

Node	Discharge (cfs)	Rim Elevation (ft)	Sump Elevation (ft)	HGL In (ft)	HGL Out (ft)	Headloss Coefficient	Description
I-2	218	1,748.90	1,737.02	1,744.22	1,743.43	0.6	Inlet[1]
I-1	2,033.00	1,746.00	1,740.00	1,744.12	1,743.29	0.5	Inlet[2]
J-1	2,251.00	1,745.00	1,729.50	1,743.01	1,737.56	1	Junction
GB-1	2,251.00	1,731.50	1,718.20	1,726.26	1,726.26	0	Grade Break
MH-1	2,251.00	1,730.40	1,714.20	1,722.53	1,722.26	0.05	Manhole
MH-2	2,251.00	1,716.20	1,702.00	1,710.33	1,710.06	0.05	Manhole
MH-3	2,251.00	1,702.10	1,688.00	1,696.33	1,696.06	0.05	Manhole
MH-4	2,251.00	1,688.20	1,674.60	1,682.93	1,682.66	0.05	Manhole
GB-2	2,251.00	1,680.00	1,667.60	1,675.66	1,675.66	0	Grade Break
MH-5	2,251.00	1,674.00	1,660.00	1,668.33	1,668.06	0.05	Manhole
GB-3	2,251.00	1,665.00	1,654.90	1,662.96	1,662.96	0	Grade Break
MH-6	2,251.00	1,661.40	1,648.00	1,656.33	1,656.06	0.05	Manhole
I-3	126	1,658.50	1,645.50	1,652.15	1,651.83	0.5	Inlet[3]
J-2	2,377.00	1,656.60	1,642.90	1,651.42	1,651.16	0.05	Junction
MH-7	2,377.00	1,643.60	1,630.70	1,639.22	1,638.96	0.05	Manhole
GB-4	2,377.00	1,637.40	1,623.80	1,633.26	1,633.26	0	Grade Break
I-4	415	1,638.50	1,620.00	1,634.95	1,634.35	0.5	Inlet[4]
J-3	2,792.00	1,635.10	1,614.05	1,632.18	1,630.66	0.31	Junction
MH-8	2,792.00	1,629.70	1,598.90	1,625.15	1,624.91	0.05	Manhole
I-5	79	1,623.00	1,612.00	1,621.26	1,621.07	0.5	Inlet[5]
J-4	2,871.00	1,622.80	1,598.10	1,620.92	1,620.30	0.12	Junction
MH-9	2,871.00	1,614.50	1,597.00	1,613.68	1,613.42	0.05	Manhole
Outlet	2,871.00	1,611.50	1,596.00	1,608.00	1,608.00		PRC Outlet

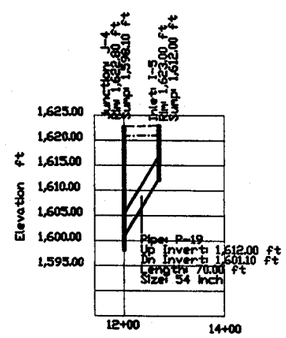
1) Sierra Pinta Channel
2) Pima Road Storm Drain
3) Downing Olson
4) Union Hills
5) Solid Waste

Appendix C

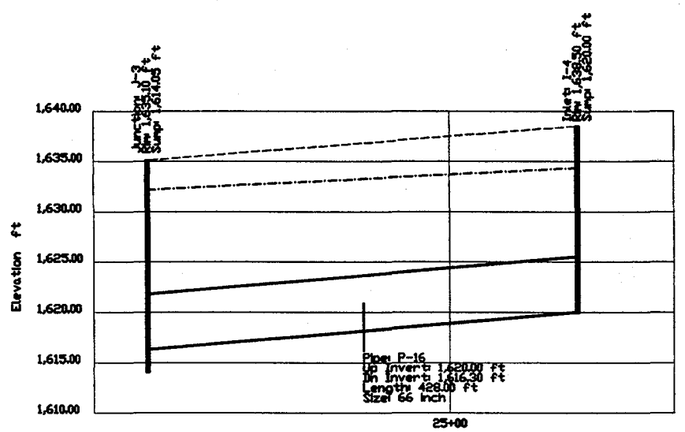
HGL Profile Plot



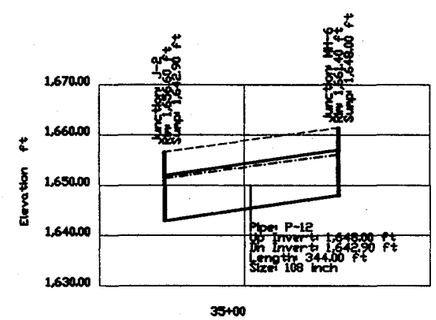
PIMA ROAD CONDUIT



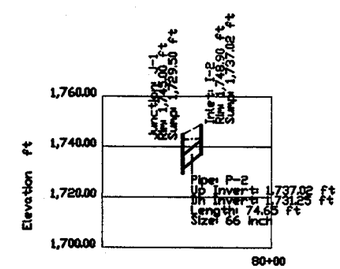
LATERAL AT
WASTE TRANSFER STATION



LATERAL AT
UNION HILLS



LATERAL AT
DOWNING OLSEN



PIMA ROAD
STORM DRAIN

Stantech Consulting Inc.
7776 Pointe Parkway W, Suite 290
Phoenix, Arizona 85044 USA
Phone: (602) 438-2200 Fax: (602) 431-9562
Fax: (602) 431-9609 (Land Development)

Appendix D

Preliminary Hydraulic Analysis Report
by D.J. Brauer, PE

CITY OF SCOTTSDALE DESERT GREENBELT
PIMA ROAD THREE BASINS PROJECT

PRELIMINARY
HYDRAULIC ANALYSES REPORT

PREPARED FOR:
STANTECH CONSULTING INC.
7776 POINTE PARKWAY WEST
SUITE 290
PHOENIX, AZ 85044

PREPARED BY:
FUTURE ENGINEERING TECHNOLOGY GROUP
2365 LOG ROAD
CALHAN, CO 80808

APRIL 13, 1998

INTRODUCTION

This report summarizes the engineering services performed for the Preliminary Hydraulic Analyses of the storm drainage pipelines for the Pima Road Three Basins Project located in Scottsdale, Arizona. The hydraulic analyses included considerations for surge pressures and operation of the pipelines in open channel and full flow conditions during flood flows. The hydraulic analyses includes consideration of empirical curve data as well as computer modeling and output results. The computer programs used as analytical tools for this report include the following:

(1) Softdesk 8 Civil/Survey Package--hydraulic calculations for open channel flow within circular conduits
(2) AutoCAD Release 14--for graphical output of pipeline profile
(3) PCWTH Version 3.0--hydraulic transient analysis for pipeline systems

The following report examines the Design Conditions, Hydraulic Analyses, Pressure Relief Features, and Recommendations for the proper operation of the storm drainage pipeline system.

DESIGN CONDITIONS

DEBRIS REMOVAL

The hydraulic analyses in this report assumes the complete removal of all debris from the flood flows that might completely block the flow within the pipelines. This removal requires adequate trashracks at all inlet flow points. These trashracks must be properly sized and maintained, especially during flood flows, to avoid blockages caused by trash and debris. Surge pressures caused by partial blockages of flows are addressed in the Hydraulic Analyses section of this report.

FRICTION LOSS

Appendix A of this report includes tables with pipeline hydraulic design data for various friction factors using Manning's coefficient "n" of 0.011, 0.012, and 0.013. These design data shown in Appendix A represent the estimated range of CIP (cast-in-place) pipe friction losses from clean water flows. The best estimate of an overall frictional coefficient for preliminary designs with clean water is a Manning's "n" value of 0.012 for CIP pipe. When sediment and debris are carried by flood flows, the equivalent frictional losses will increase based on the increase of specific gravity of the flood flow.

PIPELINE SLOPES

The critical slopes shown in Appendix A indicate that the natural ground surface slopes generally are greater than critical conditions. This indicates that open channel flows generally will be in the supercritical flow range. The computed information for flow velocities, critical slopes, and specific energies are

related to Manning's "n", so that the estimate range of "n" = 0.011 to 0.013 is necessary for preliminary designs. This information shows that design flow velocities of about 50 fps (feet per second) are possible. The significance of limiting these flow velocities, slopes, and specific energies will be discussed later in this report. However, supercritical flow conditions must be maintained within the pipelines to avoid unnecessary hydraulic jumps, which can overpressurize the pipelines as described in the Hydraulic Analyses section.

There are two areas where the pipeline slopes for the 10% design profile data should be modified. The areas are between Stations 10+00 to 26+20 and Stations 32+00 to 36+80. The first area between Stations 10+00 to 26+20 with a 0.0018 ft/ft. slope indicated should be greater than the critical slope and not produce a full flow condition. A preliminary slope of 0.0067 ft./ft. was selected, which produces a design flow depth of about 88 to 106 inches in 120 inch diameter pipelines. The second area between Stations 32+00 to 33+20 indicates a slope of 0.08125 ft./ft., which is much too steep. In order to provide adequate clearance with a 36" diameter waterline at Station 35+45, a new P.I. Station 35+50 with invert El. 1628.0 was selected. This reduces the slope to 0.0399 ft./ft., which produces design flow velocities of about 38 to 44 fps.

INTERNAL PRESSURE

A significant design condition exists with the use of CIP pipe which limits the internal pressure within the pipe to about 12 to 15 feet above the centerline of the pipelines. This is a severe hydraulic constraint, which was addressed in our January 20, 1998 letter to you. This maximum internal pressure of 12 to 15 feet must include any pressure surges, including hydraulic jumps, which will be addressed in the following Hydraulic Analyses section.

EXTERNAL LOADING

Another design condition exists with the use of CIP pipe which limits the backfill cover to about 20 feet for pipe diameters larger than 6 feet. This external load limitation has a major impact on the pipelines between Stations 13+00 to 30+00 beneath the proposed Union Hills Drive. Solutions for this problem will be discussed later in this report.

AIR ENTRAINMENT

The air inlet and venting for the pipelines must also be considered in the preliminary designs of the pipelines. Consideration of air flow is very important, especially with flows within CIP pipe. Unsteady flow conditions, including hydraulic jumps, enhance the possibility of air flow problems within pipelines. These air flow problems can cause substantial pressures surges. This air flow consideration will be addressed in the following sections.

HYDRAULIC ANALYSES

Two major considerations must be addressed with the hydraulic analyses of the storm drainage pipelines. The first is associated with the hydraulic jump occurring in the open channel flow condition and the second is unsteady flow during a full or pressurized flow condition. The internal pressure limitation of 12

to 15 feet for use of CIP pipe, as previously discussed, is a severe hydraulic constraint that can be exceeded by either of these flow conditions.

HYDRAULIC JUMP

The hydraulic jump can cause a pressure surge within a pipeline system. This pressure surge should be avoided by minimizing the potential for the occurrence of hydraulic jumps within the pipelines. The pipeline slope should be greater than critical slope to maintain open channel and supercritical flow conditions, as shown in the previous Pipeline Slopes section. The specific energy (water depth plus velocity head) and Froude number of a flow condition, as shown in Appendix A, can be used to estimate the potential pressure surge. The sequent water depth or pressure after a hydraulic jump is indicative of the steady state internal pressure that would be on the pipeline downstream of a jump. However, the surge pressure is an instantaneous loading of the sequent depth or internal pressure that occurs after the jump. The surge pressure is equivalent to about twice the sequent depth or pressure exerted above the crown (top) of the pipeline.

This surge pressure from a hydraulic jump is reduced by the energy loss dissipated in the jump. The range of design Froude numbers for this project are between 1.3 and 4.6. The estimated energy losses in a jump range from 0% loss with Froude numbers between 1.3 to about 2 and up to a maximum loss of 45% of the specific energy for a Froude number around 4.6. These energy losses are based on a USBR (U.S. Bureau of Reclamation) curve, as shown in Appendix B, for jumps on a horizontal floor, but can be used as preliminary analytical estimates for this project.

For example, assume a Manning's "n" = 0.012 and examine Sta. 33+00 with the following design data from Appendix A:

Pipeline station =	33+00
Pipe diameter =	9.5 ft.
Pipe slope =	0.0399 ft./ft.
Invert elevation =	1618.0 ft.
Flow depth =	48.8 in.
Specific energy =	30.2 ft.
Froude number =	4.1

From the Appendix B curve, the estimated hydraulic jump energy loss is about 40% of the specific energy or about 12.1 feet. The sequent depth produces a pressure level at El. 1636.1 (El. 1618.0 + 30.2 ft. - 12.1 ft.) which is an excess pressure of 8.6 ft.(30.2 ft. - 12.1 ft. - 9.5 ft.) above the crown of the pipe. The pressure surge can be estimated to be about 2 times the 8.6 ft. overpressure for a total pressure above pipe centerline of about 22 feet (9.5 ft./2 + 2(8.6 ft.)). This 22 ft surge pressure exceeds the maximum allowable internal pressure of CIP pipe of 15 feet by over 46%, which is <u>not</u> acceptable. If the external soil backfill is compacted with a depth of 5 ft. to 15 ft. cover, then a maximum surge pressure of about 20% overpressure or about 18 feet above pipe centerline could

possibly be used. This absolute limit of 18 feet of internal pressure may be allowed for CIP pipe at the preliminary design level, but only after verification and refinement from more detailed analysis and designs..

Another problem associated with hydraulic jumps within pipelines is that of air entrainment within the water flows. Using the graph shown in Appendix C, the approximate air entrainment for the above example would be about 3.2% of the water flow or about 38 cfs (cubic feet per second). This entrained air must be properly transported or released from the pipeline system. The entrained air can produce potential blockage or air blowback problems that not only hinder the water flow, but also can cause significant damage to the pipeline system. Solutions to this potential problem will be discussed in the Pressure Relief Features section.

UNSTEADY FULL FLOW

The CIP pipelines can function properly in a pressurized or full flow condition. However, during a full flow condition, the 15 ft. maximum internal pressure can be quickly and easily exceeded, especially during unsteady flow conditions. Occurrences of any unsteady full flow condition should be minimized to obtain the best full flow conditions possible. The areas where there is the greatest risk of unsteady flow are at the inlets due to debris and trash clogging, changing uncontrolled flows, and entrainment and exhaust of air flows.

The removal of debris and trash before flood flows enter the pipelines is critical for the successful operation of the storm drainage system. Examination of the effect of potential flow blockage due to debris or trash clogging was done with a computer model using the PCWTH computer program. As shown in Appendix D, a full-flow surge analysis for a 75% flow blockage in the existing system with no air vents was performed. This computer model is approximate, but adequate for preliminary designs. Assumptions made include the following data as shown in "Pipe Line Data" output: transient celerity = 3,500 ft./sec with sediment flow, pressurized flow = 1,431 cfs in each pipeline throughout the length; and Darcy's friction factors "f" = 0.020 to 0.025 for increased specific gravity of sediment flows. The "Steady State Analysis" shows a continuous flow through each pipeline and at Line 1 (near Station 86+44) begins with a water surface El. 1735 and the last station at Line 17 (near Station 10+00) has a water surface El. 1598. These water surface elevations are not as important as the change in pressure during unsteady flow conditions, as the program assumes full-flow or pressurized conditions. The flow blockage is simulated to occur near Station 10+50, which closes off 75% of the C_v flow factor at that point in 2 seconds.

The results of the surge analysis are shown in the "Final Results of Analysis" output which indicate that transients of over 30 feet surge pressure occur throughout the pipeline length. These surge pressures are shown in the "DH Max" column of the output page. These internal pressures violate the 15 ft. maximum allowable pressure and are not acceptable. This analysis demonstrates the importance of debris and trash removal from the pipeline flows.

The inlet flow junction structures must have adequate debris removal and also must produce controlled transitions into both of the main pipeline flows. The inlet flows can cause hydraulic jumps and surge pressures that exceed the

maximum allowable pressure. The inlet flow junction structures must control the inlet flows and train them into steady supercritical flows for the two main pipelines.

The entrainment and exhaust of air flows must also be considered in the inlet flow junction structure designs. Air blowback can be a critical safety and operational problem. As shown in Appendix E, there are USBR design curves for air inlets of free flow siphon pipelines. The inlets on the upper right side of these curves have produced operational problems with air flow and blowback. The design data for the critical areas of this project have been plotted in the red range on the curve. This curve indicates that the air inlets for this project are marginal at best for providing trouble-free operation.

PRESSURE RELIEF FEATURES

The most severe constraint with the use of CIP pipelines is the 15 ft. maximum allowable internal pressure. If the external soil backfill is compacted with a depth of 5 ft. to 15 ft. cover, then a maximum surge pressure of about 20% overpressure or about 18 feet above pipe centerline possibly could be used. This 18 foot pressure limit may be allowed for CIP pipe at the preliminary design level, but must be adjusted with more detailed designs. This hydraulic constraint requires that some form of pressure relief be placed at pipeline locations that do not allow the internal pressure limit to be exceeded throughout both pipelines.

Since manhole structures must be provided at certain intervals along each pipeline for maintenance reasons, then some of these structures can also serve as pressure relief features. The pressure relief function can be achieved when these manhole access areas act as a surge tank. The surge tank provides an open water surface to reflect and reduce the surge pressures in a closed, pressurized pipeline. The surge tank can also overflow, which immediately will reduce the internal pressure to the pressure of the overflow water surface. These overflow vent structures, acting as surge tanks, must be properly sized and located to minimize costs, yet provide adequate pressure relief for the pipelines.

Appendix F shows two surge analyses computer models which have similar results. In the development of these models, it is assumed that adequate debris removal has been performed on the flood flows, that a maximum 25% flow blockage occurs, and that twelve 5 ft. x 25 ft. overflow vent structures are provided along the pipelines. The computer model is similar to the one described in the Unsteady Full Flow section with the same layout. As the computer output results indicate in the "Final Results of Analysis" page in column "DH Max" that surge pressures in the range of 0.2 to 1.6 feet are produced with a flow blockage of 25%. These surge pressures are only about 10% above the steady state pressures, which is an acceptable level of pressure relief. However, the size and cost of these overflow vent structures can be reduced as shown in the other computer model results in Appendix F.

This computer model is nearly identical to the previous one, but ten of the overflow vent structures are reduced to 5-foot diameter vents on each pipeline. This only slightly increased the "DH Max" pressures to between 0.5 to 1.6 feet

above steady state pressures. This computer model results show only about 10% surge pressures above the steady state pressures, which is an acceptable level of pressure relief. The cost of these pressure relief features is reduced by providing most of the overflow vent structures as enlarged manhole structures.

These overflow vent structures also provide frequent and large-sized air inlet and exhaust vents for the better protection against air blowback problems. Since this pipeline system is in the marginal range of operation for air inlets, as shown in Appendix E, then the twelve overflow vent structures are preferred over a reduced number of structures.

RECOMMENDATIONS

The proper removal of debris and trash from the flood drainage before the flows enter the pipelines is essential for the successful operation of the storm drainage system. Adequate debris removal systems must be provided at every inlet flow point along the pipelines. These inlet flow junction structures must be carefully designed to introduce the inflows without hydraulic jumps or excessive turbulence into the pipeline flows. The inlet flow structures must control and equally distribute the inflows into both pipelines as steady supercritical flows.

There are two areas where the pipeline slopes should be modified to maintain supercritical flows throughout the storm drainage pipelines length to the exit where an energy dissipation structure should be provided. The pipeline slope between Stations 10+00 to 26+20 should be changed to a slope of 0.0067 ft./ft. or greater. The other area between Stations 32+00 to 35+50 should have a slope of 0.0399 ft./ft. or less, if possible.

The changed slope between Stations 10+00 to 26+20 does increase the level of external soil backfill cover under the proposed Union Hills Drive alignment beyond the 20 ft. maximum allowable limit. This 20 ft. maximum limit of backfill can be adjusted to accommodate the actual soil conditions and backfill in later detailed designs. However, it is likely that the maximum allowable backfill loading still will be exceeded beneath the Union Hills Drive alignment.

A lightweight fill over the pipelines should be used to achieve an acceptable level of external loading. Lightweight foam blocks have been successfully used in highway embankments to reduce the external loading and not settle or break down over time. These foam blocks should extend a short distance past the critical backfill areas and cover both pipelines.

The use of overflow vent structures is highly recommended. Appendix G contains a table which shows the proposed locations and sizes of the twelve overflow vent structures. In consideration of the internal pressure constraint, this table shows the minimum number of structures that is required to ensure that the vertical change in vent top elevations does not exceed about 14 feet. Also included in Appendix G is a graphical display of the pipeline system with the proposed overflow vent structures. The steady state supercritical flow water surface is also shown for the design flood flows and a Manning's "n" of 0.012. The overflow vent structures are mostly 5 ft. diameter manhole structures with one on each pipeline at the stations shown. There are 5 ft. x 25 ft. overflow vent structures at Stations 10+50 and 86+44 to ensure an adequate air flow at the start and end of the large pipelines. The structure at Station 10+50 should

transport water overflows through a 5 ft. x 7 ft. or larger conduit or channel horizontally from the top of the vent at El. 1606.0 to daylight for open channel overflows. The overflow vent structures at Stations 22+00 and 28+00 must have 5 ft. wide by 7 ft. high outlet conduits which convey water/air horizontally for several hundred feet beneath the roadway fill of the Union Hills Drive.

Each of the overflow vent structures must have a substantial grating system located at the top of each vent opening for safety and for functional uses. The vent grating must have adequate opening areas to allow significant air inflow and exhaust to occur without hindrance. The grating must be securely anchored to accommodate external vehicle loadings and also to resist vertical upward water pressure loadings from blowback or overpressure conditions. Considerations must also be given to exclude trash, wind-blown sand, and other debris from entering the vents, especially during times of no storm drainage flows.

The use of the overflow vent structures in connection with the storm drainage pipelines should provide a successfully operational system, if the above recommendations are included in the later designs. The proposed vent sizes and locations are not finalized, but should provide adequate information for establishing further preliminary system designs.

CONTENTS

	Page
INTRODUCTION	1
DESIGN CONDITIONS	1
Debris Removal	1
Friction Loss	1
Pipeline Slopes	1
Internal Pressure	2
External Loading	2
Air Entrainment	2
HYDRAULIC ANALYSES	2
Hydraulic Jump	3
Unsteady Full Flow	4
PRESSURE RELIEF FEATURES	5
RECOMMENDATIONS	6

APPENDICES

Appendix A--Pipeline Hydraulic Design Data Tables
Appendix B--USBR- Hydraulic Jump Energy Loss
Appendix C--USBR- Air Entrainment Curve
Appendix D--Program PCWTH Output-75% Flow Blockage with No Vents
Appendix E--USBR Siphon Inlet Design Curves
Appendix F--Program PCWTH Output-25% Flow Blockage with Air Vents
Appendix G--Summary Table and Graph for Overflow Vent Structures

APPENDIX A

PIPELINE HYDRAULIC DESIGN DATA TABLES

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.011

	Sta. 10+00	Sta. 10+50	Sta. 15+40	Sta. 22+00	Sta. 22+00	Sta. 26+20
Given Input Data:						
Diameter	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Flowrate	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1391.5000 cfs	1391.5000 cfs
Slope	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0261 ft/ft
Invert Elevation	1588.0500* ft	1588.3800* ft	1591.6600* ft	1596.0900* ft	1596.0900* ft	1598.9000 ft
Computed Results:						
Depth	88.5479 in	88.5479 in	88.5479 in	88.5479 in	86.5471 in	55.7622 in
Area	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2
Wetted Area	62.1289 ft2	62.1289 ft2	62.1289 ft2	62.1289 ft2	60.6479 ft2	35.7414 ft2
Wetted Perimeter	248.0000 in	248.0000 in	248.0000 in	248.0000 in	243.4953 in	180.0129 in
Perimeter	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in
Velocity	23.0327 fps	23.0327 fps	23.0327 fps	23.0327 fps	22.9439 fps	38.9325 fps
Hydraulic Radius	36.0749 in	36.0749 in	36.0749 in	36.0749 in	35.8664 in	28.5910 in
Full flow flowrate	1599.7302 cfs	1599.7302 cfs	1599.7302 cfs	1599.7302 cfs	1599.7302 cfs	3157.4000 cfs
Full flow velocity	20.3684 fps	20.3684 fps	20.3684 fps	20.3684 fps	20.3684 fps	40.2013 fps
Critical Information:						
Critical Depth	116.0982 in	116.0982 in	116.0982 in	116.0982 in	114.1899 in	114.1899 in
Critical slope	0.0029 ft/ft	0.0029 ft/ft	0.0029 ft/ft	0.0029 ft/ft	0.0029 ft/ft	0.0029 ft/ft
Critical velocity	16.6360 fps	16.6360 fps	16.6360 fps	16.6360 fps	16.4815 fps	16.4815 fps
Critical area	86.0184 ft2	86.0184 ft2	86.0184 ft2	86.0184 ft2	84.4281 ft2	84.4281 ft2
Critical perimeter	300.6920 in	300.6920 in	300.6920 in	300.6920 in	296.8753 in	296.8753 in
Critical hydraulic radius	41.1938 in	41.1938 in	41.1938 in	41.1938 in	40.9520 in	40.9520 in
Critical top width	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Specific energy	15.6351 ft	15.6351 ft	15.6351 ft	15.6351 ft	15.4030 ft	28.2022 ft
Minimum energy	14.5123 ft	14.5123 ft	14.5123 ft	14.5123 ft	14.2737 ft	14.2737 ft
Froude number	1.6537	1.6537	1.6537	1.6537	1.6625	3.6260
Flow Condition	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.011

	Sta. 28+00		Sta. 32+00		Sta. 32+00		Sta. 33+00		Sta. 35+50*		Sta. 36+80	
Given Input Data:												
Diameter	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Flowrate	1391.5000	cfs	1391.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs
Slope	0.0261	ft/ft	0.0261	ft/ft	0.0399*	ft/ft	0.0399*	ft/ft	0.0208*	ft/ft	0.0185*	ft/ft
Invert Elevation	1603.6000	ft	1614.0500	ft	1614.0500	ft	1618.0000	ft	1628.0000*	ft	1630.7000	ft
Computed Results:												
Depth	55.7622	in	55.7622	in	46.4887	in	46.4887	in	55.8864	in	57.8468	in
Area	78.5398	ft2	78.5398	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2
Wetted Area	35.7414	ft2	35.7414	ft2	27.1670	ft2	27.1670	ft2	34.5595	ft2	36.1115	ft2
Wetted Perimeter	180.0129	in	180.0129	in	157.9271	in	157.9271	in	176.8434	in	180.7645	in
Perimeter	376.9911	in	376.9911	in	358.1416	in	358.1416	in	358.1416	in	358.1416	in
Velocity	38.9325	fps	38.9325	fps	43.7479	fps	43.7479	fps	34.3899	fps	32.9120	fps
Hydraulic Radius	28.5910	in	28.5910	in	24.7713	in	24.7713	in	28.1411	in	28.7670	in
Full flow flowrate	3157.4000	cfs	3157.4000	cfs	3404.8037	cfs	3404.8037	cfs	2458.3137	cfs	2318.4167	cfs
Full flow velocity	40.2013	fps	40.2013	fps	48.0347	fps	48.0347	fps	34.6817	fps	32.7080	fps
Critical Information:												
Critical Depth	114.1899	in	114.1899	in	106.6087	in	106.6087	in	106.6087	in	106.6087	in
Critical slope	0.0029	ft/ft	0.0029	ft/ft	0.0029	ft/ft	0.0029	ft/ft	0.0029	ft/ft	0.0029	ft/ft
Critical velocity	16.4815	fps	16.4815	fps	15.9072	fps	15.9072	fps	15.9072	fps	15.9072	fps
Critical area	84.4281	ft2	84.4281	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2
Critical perimeter	296.8753	in	296.8753	in	278.2881	in	278.2881	in	278.2881	in	278.2881	in
Critical hydraulic radius	40.9520	in	40.9520	in	38.6610	in	38.6610	in	38.6610	in	38.6610	in
Critical top width	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Specific energy	28.2022	ft	28.2022	ft	33.6167	ft	33.6167	ft	23.0364	ft	21.6540	ft
Minimum energy	14.2737	ft	14.2737	ft	13.3261	ft	13.3261	ft	13.3261	ft	13.3261	ft
Froude number	3.6260		3.6260		4.5216		4.5216		3.1784		2.9761	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.011

	Sta. 39+00		Sta. 43+40		Sta. 43+40		Sta. 46+84		Sta. 48+60		Sta. 53+44	
Given Input Data:												
Diameter	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1188.5000	cfs	1188.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0185	ft/ft	0.0185	ft/ft	0.0148	ft/ft	0.0392	ft/ft	0.0105	ft/ft	0.0322	ft/ft
Invert Elevation	1634.8000	ft	1642.9000	ft	1642.9000	ft	1648.0000	ft	1654.9000	ft	1660.0000	ft
Computed Results:												
Depth	57.8468	in	57.8468	in	61.9808	in	46.5123	in	69.4170	in	49.1605	in
Area	70.8822	ft2	70.8822	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2
Wetted Area	36.1115	ft2	36.1115	ft2	37.7723	ft2	26.2109	ft2	43.2123	ft2	28.1839	ft2
Wetted Perimeter	180.7645	in	180.7645	in	185.6662	in	154.6222	in	200.9149	in	159.9540	in
Perimeter	358.1416	in	358.1416	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in
Velocity	32.9120	fps	32.9120	fps	29.7969	fps	42.9401	fps	26.0458	fps	39.9342	fps
Hydraulic Radius	28.7670	in	28.7670	in	29.2957	in	24.4103	in	30.9712	in	25.3728	in
Full flow flowrate	2318.4167	cfs	2318.4167	cfs	1795.2305	cfs	2921.6784	cfs	1512.1122	cfs	2647.9959	cfs
Full flow velocity	32.7080	fps	32.7080	fps	28.2192	fps	45.9259	fps	23.7689	fps	41.6239	fps
Critical Information:												
Critical Depth	106.6087	in	106.6087	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in
Critical slope	0.0029	ft/ft	0.0029	ft/ft	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft
Critical velocity	15.9072	fps	15.9072	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	74.7146	ft2	74.7146	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2
Critical perimeter	278.2881	in	278.2881	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	38.6610	in	38.6610	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Specific energy	21.6540	ft	21.6540	ft	18.9679	ft	32.5305	ft	16.3459	ft	28.8798	ft
Minimum energy	13.3261	ft	13.3261	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.9761		2.9761		2.5654		4.4145		2.1026		3.9704	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.011

	Sta. 55+80		Sta. 60+04		Sta. 66+64		Sta. 73+24		Sta. 79+84		Sta. 86+44	
Given Input Data:												
Diameter	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0165	ft/ft	0.0203	ft/ft	0.0212	ft/ft	0.0185	ft/ft	0.0189	ft/ft	0.0252	ft/ft
Invert Elevation	1667.6000	ft	1674.6000	ft	1688.0000	ft	1702.0000	ft	1714.2000	ft	1729.5000	ft
Computed Results:												
Depth	59.9042	in	56.2356	in	55.5106	in	57.8354	in	57.4608	in	52.7528	in
Area	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2
Wetted Area	36.2279	ft2	33.4848	ft2	32.9415	ft2	34.6828	ft2	34.4025	ft2	30.8733	ft2
Wetted Perimeter	181.4781	in	174.1185	in	172.6677	in	177.3234	in	176.5724	in	167.1513	in
Perimeter	339.2920	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in
Velocity	31.0672	fps	33.6122	fps	34.1667	fps	32.4513	fps	32.7157	fps	36.4555	fps
Hydraulic Radius	28.7463	in	27.6927	in	27.4723	in	28.1651	in	28.0562	in	26.5972	in
Full flow flowrate	1895.5330	cfs	2102.5067	cfs	2148.6086	cfs	2007.1288	cfs	2028.7114	cfs	2342.5542	cfs
Full flow velocity	29.7959	fps	33.0493	fps	33.7740	fps	31.5501	fps	31.8893	fps	36.8226	fps
Critical Information:												
Critical Depth	105.9399	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in
Critical slope	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft	0.0031	ft/ft
Critical velocity	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2
Critical perimeter	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Specific energy	19.9937	ft	22.2438	ft	22.7673	ft	21.1859	ft	21.4222	ft	25.0494	ft
Minimum energy	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.7305		3.0722		3.1485		2.9145		2.9502		3.4696	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.012

	Sta. 10+00	Sta. 10+50	Sta. 15+40	Sta. 22+00	Sta. 22+00	Sta. 26+20
Given Input Data:						
Diameter	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Flowrate	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1391.5000 cfs	1391.5000 cfs
Slope	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0261 ft/ft
Invert Elevation	1588.0500* ft	1588.3800* ft	1591.6600* ft	1596.0900* ft	1596.0900* ft	1598.9000 ft
Computed Results:						
Depth	95.8383 in	95.8383 in	95.8383 in	95.8383 in	93.2661 in	58.6367 in
Area	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2
Wetted Area	67.2495 ft2	67.2495 ft2	67.2495 ft2	67.2495 ft2	65.4974 ft2	38.1340 ft2
Wetted Perimeter	265.3119 in	265.3119 in	265.3119 in	265.3119 in	259.0177 in	185.7688 in
Perimeter	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in
Velocity	21.2790 fps	21.2790 fps	21.2790 fps	21.2790 fps	21.2451 fps	36.4898 fps
Hydraulic Radius	36.5002 in	36.5002 in	36.5002 in	36.5002 in	36.4131 in	29.5598 in
Full flow flowrate	1466.4194 cfs	1466.4194 cfs	1466.4194 cfs	1466.4194 cfs	1466.4194 cfs	2894.2833 cfs
Full flow velocity	18.6710 fps	18.6710 fps	18.6710 fps	18.6710 fps	18.6710 fps	36.8512 fps
Critical Information:						
Critical Depth	116.0982 in	116.0982 in	116.0982 in	116.0982 in	114.1899 in	114.1899 in
Critical slope	0.0035 ft/ft	0.0035 ft/ft	0.0035 ft/ft	0.0035 ft/ft	0.0034 ft/ft	0.0034 ft/ft
Critical velocity	16.6360 fps	16.6360 fps	16.6360 fps	16.6360 fps	16.4815 fps	16.4815 fps
Critical area	86.0184 ft2	86.0184 ft2	86.0184 ft2	86.0184 ft2	84.4281 ft2	84.4281 ft2
Critical perimeter	300.6920 in	300.6920 in	300.6920 in	300.6920 in	296.8753 in	296.8753 in
Critical hydraulic radius	41.1938 in	41.1938 in	41.1938 in	41.1938 in	40.9520 in	40.9520 in
Critical top width	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Specific energy	14.9873 ft	14.9873 ft	14.9873 ft	14.9873 ft	14.7597 ft	25.5786 ft
Minimum energy	14.5123 ft	14.5123 ft	14.5123 ft	14.5123 ft	14.2737 ft	14.2737 ft
Froude number	1.4903	1.4903	1.4903	1.4903	1.4986	3.2939
Flow Condition	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.012

	Sta. 28+00		Sta. 32+00		Sta. 32+00		Sta. 33+00		Sta. 35+50*		Sta. 36+80	
Given Input Data:												
Diameter	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Flowrate	1391.5000	cfs	1391.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs
Slope	0.0261	ft/ft	0.0261	ft/ft	0.0399*	ft/ft	0.0399*	ft/ft	0.0208*	ft/ft	0.0185*	ft/ft
Invert Elevation	1603.6000	ft	1614.0500	ft	1614.0500	ft	1618.0000	ft	1628.0000*	ft	1630.7000	ft
Computed Results:												
Depth	58.6367	in	58.6367	in	48.7811	in	48.7811	in	58.8336	in	60.9482	in
Area	78.5398	ft2	78.5398	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2
Wetted Area	38.1340	ft2	38.1340	ft2	28.9571	ft2	28.9571	ft2	36.8925	ft2	38.5643	ft2
Wetted Perimeter	185.7688	in	185.7688	in	162.5755	in	162.5755	in	182.7387	in	186.9735	in
Perimeter	376.9911	in	376.9911	in	358.1416	in	358.1416	in	358.1416	in	358.1416	in
Velocity	36.4898	fps	36.4898	fps	41.0435	fps	41.0435	fps	32.2153	fps	30.8187	fps
Hydraulic Radius	29.5598	in	29.5598	in	25.6485	in	25.6485	in	29.0717	in	29.7007	in
Full flow flowrate	2894.2833	cfs	2894.2833	cfs	3121.0700	cfs	3121.0700	cfs	2253.4542	cfs	2125.2153	cfs
Full flow velocity	36.8512	fps	36.8512	fps	44.0318	fps	44.0318	fps	31.7915	fps	29.9824	fps
Critical Information:												
Critical Depth	114.1899	in	114.1899	in	106.6087	in	106.6087	in	106.6087	in	106.6087	in
Critical slope	0.0034	ft/ft	0.0034	ft/ft	0.0035	ft/ft	0.0035	ft/ft	0.0035	ft/ft	0.0035	ft/ft
Critical velocity	16.4815	fps	16.4815	fps	15.9072	fps	15.9072	fps	15.9072	fps	15.9072	fps
Critical area	84.4281	ft2	84.4281	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2
Critical perimeter	296.8753	in	296.8753	in	278.2881	in	278.2881	in	278.2881	in	278.2881	in
Critical hydraulic radius	40.9520	in	40.9520	in	38.6610	in	38.6610	in	38.6610	in	38.6610	in
Critical top width	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Specific energy	25.5786	ft	25.5786	ft	30.2442	ft	30.2442	ft	21.0312	ft	19.8399	ft
Minimum energy	14.2737	ft	14.2737	ft	13.3261	ft	13.3261	ft	13.3261	ft	13.3261	ft
Froude number	3.2939		3.2939		4.1228		4.1228		2.8821		2.6968	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.012

	Sta. 39+00		Sta. 43+40		Sta. 43+40		Sta. 46+84		Sta. 48+60		Sta. 53+44	
Given Input Data:												
Diameter	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1188.5000	cfs	1188.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0185	ft/ft	0.0185	ft/ft	0.0148	ft/ft	0.0392	ft/ft	0.0105	ft/ft	0.0322	ft/ft
Invert Elevation	1634.8000	ft	1642.9000	ft	1642.9000	ft	1648.0000	ft	1654.9000	ft	1660.0000	ft
Computed Results:												
Depth	60.9482	in	60.9482	in	65.5631	in	48.8450	in	73.8765	in	51.6746	in
Area	70.8822	ft2	70.8822	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2
Wetted Area	38.5643	ft2	38.5643	ft2	40.4142	ft2	27.9483	ft2	46.3722	ft2	30.0651	ft2
Wetted Perimeter	186.9735	in	186.9735	in	192.9527	in	159.3203	in	210.3563	in	164.9937	in
Perimeter	358.1416	in	358.1416	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in
Velocity	30.8187	fps	30.8187	fps	27.8491	fps	40.2708	fps	24.2710	fps	37.4355	fps
Hydraulic Radius	29.7007	in	29.7007	in	30.1610	in	25.2608	in	31.7442	in	26.2396	in
Full flow flowrate	2125.2153	cfs	2125.2153	cfs	1645.6280	cfs	2678.2052	cfs	1386.1029	cfs	2427.3296	cfs
Full flow velocity	29.9824	fps	29.9824	fps	25.8676	fps	42.0987	fps	21.7882	fps	38.1552	fps
Critical Information:												
Critical Depth	106.6087	in	106.6087	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in
Critical slope	0.0035	ft/ft	0.0035	ft/ft	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft
Critical velocity	15.9072	fps	15.9072	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	74.7146	ft2	74.7146	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2
Critical perimeter	278.2881	in	278.2881	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	38.6610	in	38.6610	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Specific energy	19.8399	ft	19.8399	ft	17.5278	ft	29.2731	ft	15.3350	ft	26.0849	ft
Minimum energy	13.3261	ft	13.3261	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.6968		2.6968		2.3203		4.0196		1.8984		3.6093	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.012

	Sta. 55+80		Sta. 60+04		Sta. 66+64		Sta. 73+24		Sta. 79+84		Sta. 86+44	
Given Input Data:												
Diameter	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0165	ft/ft	0.0203	ft/ft	0.0212	ft/ft	0.0185	ft/ft	0.0189	ft/ft	0.0252	ft/ft
Invert Elevation	1667.6000	ft	1674.6000	ft	1688.0000	ft	1702.0000	ft	1714.2000	ft	1729.5000	ft
Computed Results:												
Depth	63.2849	in	59.2915	in	58.5064	in	61.0285	in	60.6212	in	55.5302	in
Area	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2
Wetted Area	38.7378	ft2	35.7709	ft2	35.1845	ft2	37.0651	ft2	36.7621	ft2	32.9561	ft2
Wetted Perimeter	188.3085	in	180.2460	in	178.6693	in	183.7430	in	182.9219	in	172.7068	in
Perimeter	339.2920	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in
Velocity	29.0543	fps	31.4641	fps	31.9885	fps	30.3655	fps	30.6158	fps	34.1515	fps
Hydraulic Radius	29.6229	in	28.5777	in	28.3572	in	29.0480	in	28.9399	in	27.4782	in
Full flow flowrate	1737.5719	cfs	1927.2978	cfs	1969.5578	cfs	1839.8680	cfs	1859.6521	cfs	2147.3413	cfs
Full flow velocity	27.3129	fps	30.2952	fps	30.9595	fps	28.9209	fps	29.2319	fps	33.7541	fps
Critical Information:												
Critical Depth	105.9399	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in
Critical slope	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft	0.0036	ft/ft
Critical velocity	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2
Critical perimeter	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Specific energy	18.3995	ft	20.3278	ft	20.7788	ft	19.4188	ft	19.6216	ft	22.7528	ft
Minimum energy	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.4708		2.7828		2.8525		2.6388		2.6714		3.1464	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.013

	Sta. 10+00	Sta. 10+50	Sta. 15+40	Sta. 22+00	Sta. 22+00	Sta. 26+20
Given Input Data:						
Diameter	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Flowrate	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1431.0000 cfs	1391.5000 cfs	1391.5000 cfs
Slope	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0067* ft/ft	0.0261 ft/ft
Invert Elevation	1588.0500* ft	1588.3800* ft	1591.6600* ft	1596.0900* ft	1596.0900* ft	1598.9000 ft
Computed Results:						
Depth	106.1473 in	106.1473 in	106.1473 in	106.1473 in	101.6774 in	61.4686 in
Area	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2	78.5398 ft2
Wetted Area	73.4952 ft2	73.4952 ft2	73.4952 ft2	73.4952 ft2	70.9596 ft2	40.4936 ft2
Wetted Perimeter	293.7915 in	293.7915 in	293.7915 in	293.7915 in	280.6430 in	191.4331 in
Perimeter	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in	376.9911 in
Velocity	19.4706 fps	19.4706 fps	19.4706 fps	19.4706 fps	19.6097 fps	34.3634 fps
Hydraulic Radius	36.0232 in	36.0232 in	36.0232 in	36.0232 in	36.4099 in	30.4602 in
Full flow flowrate	1353.6179 cfs	1353.6179 cfs	1353.6179 cfs	1353.6179 cfs	1353.6179 cfs	2671.6461 cfs
Full flow velocity	17.2348 fps	17.2348 fps	17.2348 fps	17.2348 fps	17.2348 fps	34.0165 fps
Critical Information:						
Critical Depth	116.0982 in	116.0982 in	116.0982 in	116.0982 in	114.1899 in	114.1899 in
Critical slope	0.0041 ft/ft	0.0041 ft/ft	0.0041 ft/ft	0.0041 ft/ft	0.0040 ft/ft	0.0040 ft/ft
Critical velocity	16.6360 fps	16.6360 fps	16.6360 fps	16.6360 fps	16.4815 fps	16.4815 fps
Critical area	86.0184 ft2	86.0184 ft2	86.0184 ft2	86.0184 ft2	84.4281 ft2	84.4281 ft2
Critical perimeter	300.6920 in	300.6920 in	300.6920 in	300.6920 in	296.8753 in	296.8753 in
Critical hydraulic radius	41.1938 in	41.1938 in	41.1938 in	41.1938 in	40.9520 in	40.9520 in
Critical top width	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in	120.0000 in
Specific energy	14.5413 ft	14.5413 ft	14.5413 ft	14.5413 ft	14.3150 ft	23.4733 ft
Minimum energy	14.5123 ft	14.5123 ft	14.5123 ft	14.5123 ft	14.2737 ft	14.2737 ft
Froude number	1.3532	1.3532	1.3532	1.3532	1.3611	3.0106
Flow Condition	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical	Supercritical

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.013

	Sta. 28+00		Sta. 32+00		Sta. 32+00		Sta. 33+00		Sta. 35+50*		Sta. 36+80	
Given Input Data:												
Diameter	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Flowrate	1391.5000	cfs	1391.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs	1188.5000	cfs
Slope	0.0261	ft/ft	0.0261	ft/ft	0.0399*	ft/ft	0.0399*	ft/ft	0.0208*	ft/ft	0.0185*	ft/ft
Invert Elevation	1603.6000	ft	1614.0500	ft	1614.0500	ft	1618.0000	ft	1628.0000*	ft	1630.7000	ft
Computed Results:												
Depth	61.4686	in	61.4686	in	51.0210	in	51.0210	in	61.7512	in	64.0300	in
Area	78.5398	ft2	78.5398	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2	70.8822	ft2
Wetted Area	40.4936	ft2	40.4936	ft2	30.7164	ft2	30.7164	ft2	39.1981	ft2	40.9924	ft2
Wetted Perimeter	191.4331	in	191.4331	in	167.0908	in	167.0908	in	188.5842	in	193.1667	in
Perimeter	376.9911	in	376.9911	in	358.1416	in	358.1416	in	358.1416	in	358.1416	in
Velocity	34.3634	fps	34.3634	fps	38.6926	fps	38.6926	fps	30.3204	fps	28.9932	fps
Hydraulic Radius	30.4602	in	30.4602	in	26.4716	in	26.4716	in	29.9311	in	30.5586	in
Full flow flowrate	2671.6461	cfs	2671.6461	cfs	2880.9877	cfs	2880.9877	cfs	2080.1116	cfs	1961.7372	cfs
Full flow velocity	34.0165	fps	34.0165	fps	40.6447	fps	40.6447	fps	29.3460	fps	27.6760	fps
Critical Information:												
Critical Depth	114.1899	in	114.1899	in	106.6087	in	106.6087	in	106.6087	in	106.6087	in
Critical slope	0.0040	ft/ft	0.0040	ft/ft	0.0041	ft/ft	0.0041	ft/ft	0.0041	ft/ft	0.0041	ft/ft
Critical velocity	16.4815	fps	16.4815	fps	15.9072	fps	15.9072	fps	15.9072	fps	15.9072	fps
Critical area	84.4281	ft2	84.4281	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2	74.7146	ft2
Critical perimeter	296.8753	in	296.8753	in	278.2881	in	278.2881	in	278.2881	in	278.2881	in
Critical hydraulic radius	40.9520	in	40.9520	in	38.6610	in	38.6610	in	38.6610	in	38.6610	in
Critical top width	120.0000	in	120.0000	in	114.0000	in	114.0000	in	114.0000	in	114.0000	in
Specific energy	23.4733	ft	23.4733	ft	27.5177	ft	27.5177	ft	19.4337	ft	18.4019	ft
Minimum energy	14.2737	ft	14.2737	ft	13.3261	ft	13.3261	ft	13.3261	ft	13.3261	ft
Froude number	3.0106		3.0106		3.7831		3.7831		2.6318		2.4614	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

* Adjusted to properly maintain supercritical flow

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.013

	Sta. 39+00		Sta. 43+40		Sta. 43+40		Sta. 46+84		Sta. 48+60		Sta. 53+44	
Given Input Data:												
Diameter	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1188.5000	cfs	1188.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0185	ft/ft	0.0185	ft/ft	0.0148	ft/ft	0.0392	ft/ft	0.0105	ft/ft	0.0322	ft/ft
Invert Elevation	1634.8000	ft	1642.9000	ft	1642.9000	ft	1648.0000	ft	1654.9000	ft	1660.0000	ft
Computed Results:												
Depth	64.0300	in	64.0300	in	69.1978	in	51.1311	in	78.6011	in	54.1474	in
Area	70.8822	ft2	70.8822	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2
Wetted Area	40.9924	ft2	40.9924	ft2	43.0547	ft2	29.6579	ft2	49.5997	ft2	31.9192	ft2
Wetted Perimeter	193.1667	in	193.1667	in	200.4579	in	163.9055	in	220.7320	in	169.9408	in
Perimeter	358.1416	in	358.1416	in	339.2920	in	339.2920	in	339.2920	in	339.2920	in
Velocity	28.9932	fps	28.9932	fps	26.1412	fps	37.9494	fps	22.6917	fps	35.2609	fps
Hydraulic Radius	30.5586	in	30.5586	in	30.9286	in	26.0561	in	32.3576	in	27.0468	in
Full flow flowrate	1961.7372	cfs	1961.7372	cfs	1519.0412	cfs	2472.1894	cfs	1279.4796	cfs	2240.6119	cfs
Full flow velocity	27.6760	fps	27.6760	fps	23.8778	fps	38.8604	fps	20.1121	fps	35.2202	fps
Critical Information:												
Critical Depth	106.6087	in	106.6087	in	105.9399	in	105.9399	in	105.9399	in	105.9399	in
Critical slope	0.0041	ft/ft	0.0041	ft/ft	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft
Critical velocity	15.9072	fps	15.9072	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	74.7146	ft2	74.7146	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2
Critical perimeter	278.2881	in	278.2881	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	38.6610	in	38.6610	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	114.0000	in	114.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Specific energy	18.4019	ft	18.4019	ft	16.4046	ft	26.6416	ft	14.5725	ft	23.8343	ft
Minimum energy	13.3261	ft	13.3261	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.4614		2.4614		2.1139		3.6829		1.7267		3.3009	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

PIMA ROAD THREE BASINS PROJECT

March 25, 1998

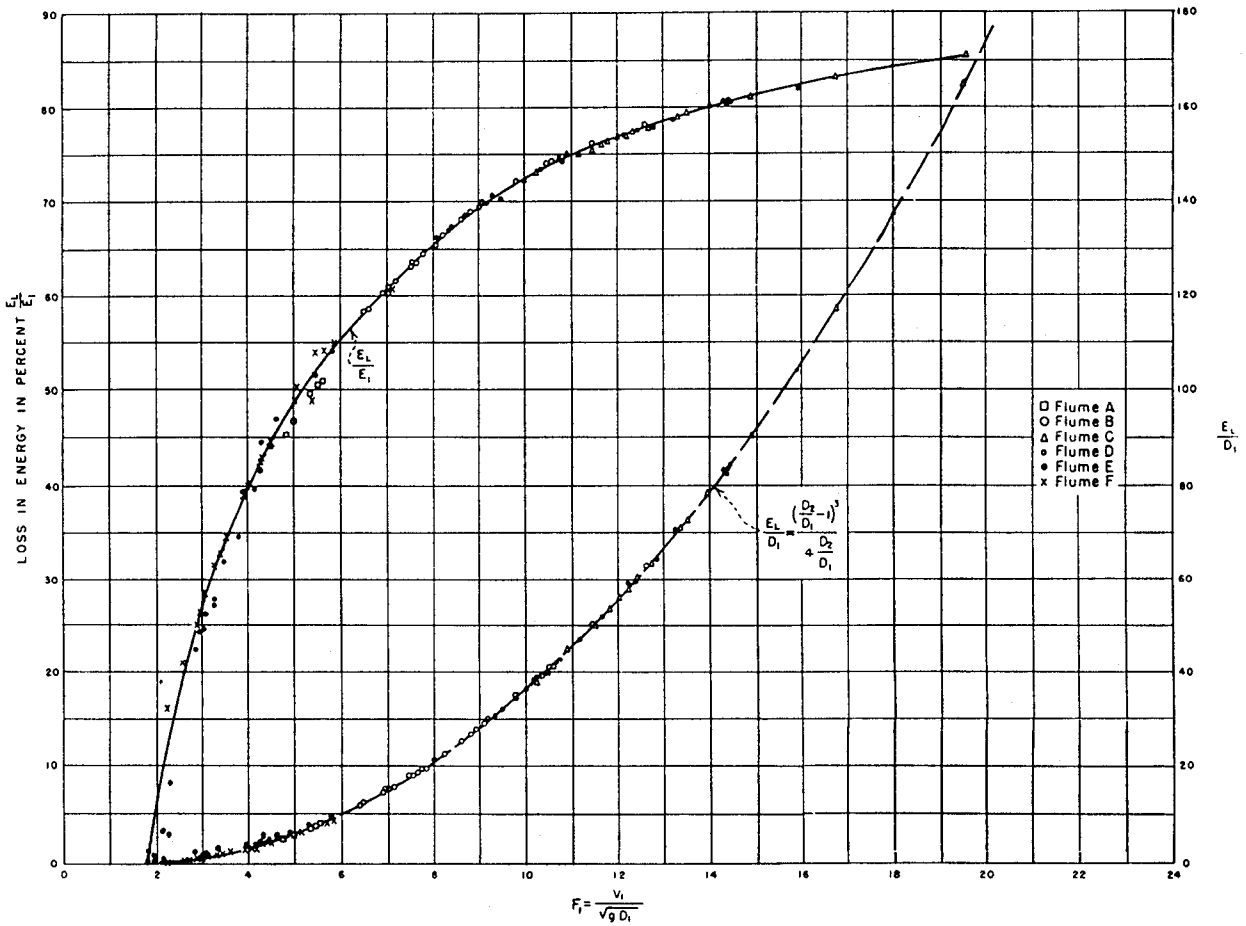
PIPELINE HYDRAULIC DESIGN DATA

MANNING'S "n" = 0.013

	Sta. 55+80		Sta. 60+04		Sta. 66+64		Sta. 73+24		Sta. 79+84		Sta. 86+44	
Given Input Data:												
Diameter	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0000	in
Flowrate	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs	1125.5000	cfs
Slope	0.0165	ft/ft	0.0203	ft/ft	0.0212	ft/ft	0.0185	ft/ft	0.0189	ft/ft	0.0252	ft/ft
Invert Elevation	1667.6000	ft	1674.6000	ft	1688.0000	ft	1702.0000	ft	1714.2000	ft	1729.5000	ft
Computed Results:												
Depth	66.6899	in	62.3381	in	61.4880	in	64.2249	in	63.7817	in	58.2786	in
Area	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6173	ft2	63.6174	ft2	63.6173	ft2
Wetted Area	41.2377	ft2	38.0372	ft2	37.4065	ft2	39.4313	ft2	39.1046	ft2	35.0142	ft2
Wetted Perimeter	195.2654	in	186.3891	in	184.6703	in	190.2201	in	189.3180	in	178.2122	in
Perimeter	339.2920	in	339.2920	in	339.2920	in	339.2920	in	339.2923	in	339.2920	in
Velocity	27.2930	fps	29.5894	fps	30.0883	fps	28.5433	fps	28.7818	fps	32.1441	fps
Hydraulic Radius	30.4111	in	29.3867	in	29.1684	in	29.8502	in	29.7439	in	28.2924	in
Full flow flowrate	1603.9125	cfs	1779.0441	cfs	1818.0534	cfs	1698.3397	cfs	1716.6062	cfs	1982.1612	cfs
Full flow velocity	25.2119	fps	27.9648	fps	28.5780	fps	26.6962	fps	26.9833	fps	31.1576	fps
Critical Information:												
Critical Depth	105.9399	in	105.9399	in	105.9399	in	105.9399	in	105.9398	in	105.9399	in
Critical slope	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft	0.0043	ft/ft
Critical velocity	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps	15.9051	fps
Critical area	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7635	ft2	70.7636	ft2	70.7635	ft2
Critical perimeter	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in	273.5257	in
Critical hydraulic radius	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in	37.2541	in
Critical top width	108.0000	in	108.0000	in	108.0000	in	108.0000	in	108.0001	in	108.0000	in
Specific energy	17.1473	ft	18.8067	ft	19.1973	ft	18.0222	ft	18.1968	ft	20.9147	ft
Minimum energy	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft	13.2425	ft
Froude number	2.2521		2.5389		2.6030		2.4065		2.4364		2.8733	
Flow Condition	Supercritical		Supercritical		Supercritical		Supercritical		Supercritical		Supercritical	

APPENDIX B

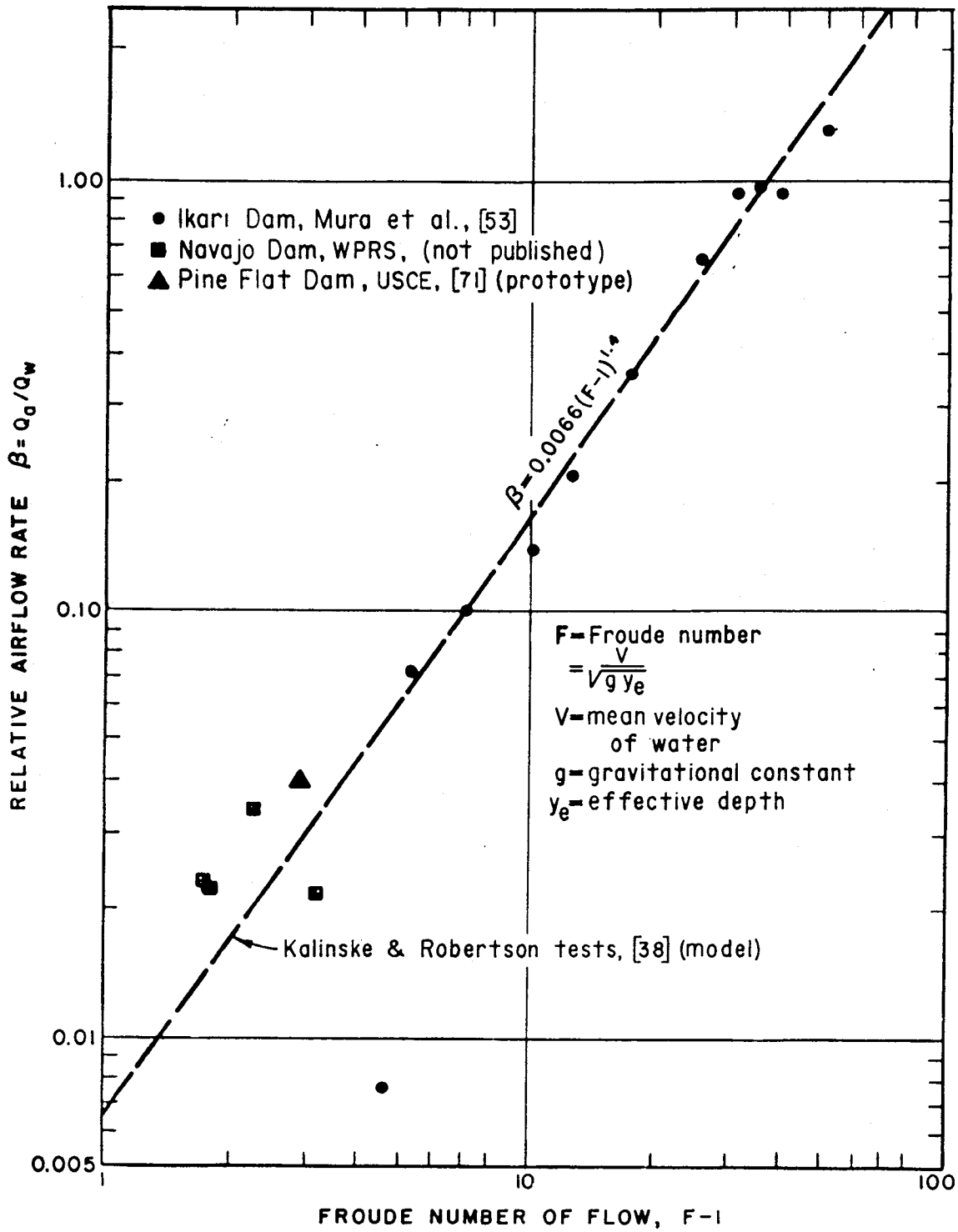
USBR--HYDRAULIC JUMP ENERGY LOSS



Loss of energy in jump on horizontal floor

APPENDIX C

USBR--AIR ENTRAINMENT CURVE



Air entrainment with hydraulic jump closing conduit.

APPENDIX D

PROGRAM PCWTH OUTPUT
75% FLOW BLOCKAGE WITH NO VENTS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 75% FLOW BLOCKAGE WITH NO OVERFLOW VENTS
17RESERVOR

1	2	1	1			
1	3	1	13			
1	4	1	13			
1	5	1	13			
1	6	1	13			
1	7	1	13			
1	8	1	13			
1	9	1	7			
1	10	1	9			
1	11	1	12			
1	12	1	2			
1	13	1	8			
1	14	1	12			
1	15	1	20			
1	16	1	3			
7	17	1	1			
2	0	0	1			
0.0000000	20.0	20.00	1735.000	1735.000	1431.000	1
3500.	9.0000	50.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	350.0	0.025000	1431.000	.999000	
3500.	9.5000	450.0	0.022500	1431.000	.999000	
3500.	9.5000	600.0	0.022500	1431.000	.999000	
3500.	9.5000	100.0	0.022500	1431.000	.999000	
3500.	10.0000	400.0	0.020000	1431.000	.999000	
3500.	10.0000	600.0	0.020000	1431.000	.999000	
3500.	10.0000	1000.0	0.020000	1431.000	.999000	
3500.	10.0000	150.0	0.020000	1431.000	.999000	
3500.	10.0000	50.0	0.020000	1431.000	.999000	
3500.	10.0000	50.0	0.020000	1431.000	.999000	
0.0	1595.000	3				
0.0	677500.0					
2.0	169375.0					
200.0	169375.0					

Program PCWTH Version 3.0 (1990)

Date: 04-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 75% FLOW BLOCKAGE WITH NO OVERFLOW VENTS

PIPE LINE DATA

Number	Dia	Celerity	Length	Flow(cfs)	Darcy F	DXPRT	DWS	Tank Dia	NBOUND	NBR	NO	NX
1	9.00	3500.0	50.0	1431.00	.025	.999	.00	.00	1	2	1	1
2	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	3	1	13
3	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	4	1	13
4	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	5	1	13
5	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	6	1	13
6	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	7	1	13
7	9.00	3500.0	650.0	1431.00	.025	.999	.00	.00	1	8	1	13
8	9.00	3500.0	350.0	1431.00	.025	.999	.00	.00	1	9	1	7
9	9.50	3500.0	450.0	1431.00	.023	.999	.00	.00	1	10	1	9
10	9.50	3500.0	600.0	1431.00	.023	.999	.00	.00	1	11	1	12
11	9.50	3500.0	100.0	1431.00	.023	.999	.00	.00	1	12	1	2
12	10.00	3500.0	400.0	1431.00	.020	.999	.00	.00	1	13	1	8
13	10.00	3500.0	600.0	1431.00	.020	.999	.00	.00	1	14	1	12
14	10.00	3500.0	1000.0	1431.00	.020	.999	.00	.00	1	15	1	20
15	10.00	3500.0	150.0	1431.00	.020	.999	.00	.00	1	16	1	3
16	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	7	17	1	1
17	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	2	0	0	1

Program PCWTH Version 3.0 (1990)

Date: 04-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 75% FLOW BLOCKAGE WITH NO OVERFLOW VENTS

STEADY STATE ANALYSIS

Time	Line	XL	H Ratio	H Change	Head	Q Ratio	Q Change	Flow	H Tank or CV	ALPHA	BETA
.000	1	.000	1.000	.000	1735.000	1.000	.000	1431.000	.000	.000	.000
.000	1	1.000	.999	.000	1733.908	1.000	.000	1431.000	.000		
.000	2	.000	.999	.000	1733.908	1.000	.000	1431.000	.000		
.000	2	1.000	.991	.000	1719.707	1.000	.000	1431.000	.000		
.000	3	.000	.991	.000	1719.707	1.000	.000	1431.000	.000		
.000	3	1.000	.983	.000	1705.506	1.000	.000	1431.000	.000		
.000	4	.000	.983	.000	1705.506	1.000	.000	1431.000	.000		
.000	4	1.000	.975	.000	1691.305	1.000	.000	1431.000	.000		
.000	5	.000	.975	.000	1691.305	1.000	.000	1431.000	.000		
.000	5	1.000	.967	.000	1677.104	1.000	.000	1431.000	.000		
.000	6	.000	.967	.000	1677.104	1.000	.000	1431.000	.000		
.000	6	1.000	.958	.000	1662.904	1.000	.000	1431.000	.000		
.000	7	.000	.958	.000	1662.904	1.000	.000	1431.000	.000		
.000	7	1.000	.950	.000	1648.703	1.000	.000	1431.000	.000		
.000	8	.000	.950	.000	1648.703	1.000	.000	1431.000	.000		
.000	8	1.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	1.000	.942	.000	1634.304	1.000	.000	1431.000	.000		
.000	10	.000	.942	.000	1634.304	1.000	.000	1431.000	.000		
.000	10	1.000	.937	.000	1625.301	1.000	.000	1431.000	.000		
.000	11	.000	.937	.000	1625.301	1.000	.000	1431.000	.000		
.000	11	1.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	1.000	.934	.000	1619.672	1.000	.000	1431.000	.000		
.000	13	.000	.934	.000	1619.672	1.000	.000	1431.000	.000		
.000	13	1.000	.930	.000	1613.480	1.000	.000	1431.000	.000		
.000	14	.000	.930	.000	1613.480	1.000	.000	1431.000	.000		
.000	14	1.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	1.000	.923	.000	1601.611	1.000	.000	1431.000	.000		
.000	16	.000	.923	.000	1601.611	1.000	.000	1431.000	677500.000		
.000	16	1.000	.923	.000	1601.095	1.000	.000	1431.000	.000		
.000	17	.000	.921	.000	1598.516	1.000	.000	1431.000	.000		
.000	17	1.000	.921	.000	1598.000	1.000	.000	1431.000	.000		

Program PCWTH Version 3.0 (1990)

Date: 04-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 75% FLOW BLOCKAGE WITH NO OVERFLOW VENTS

FINAL RESULTS OF ANALYSIS

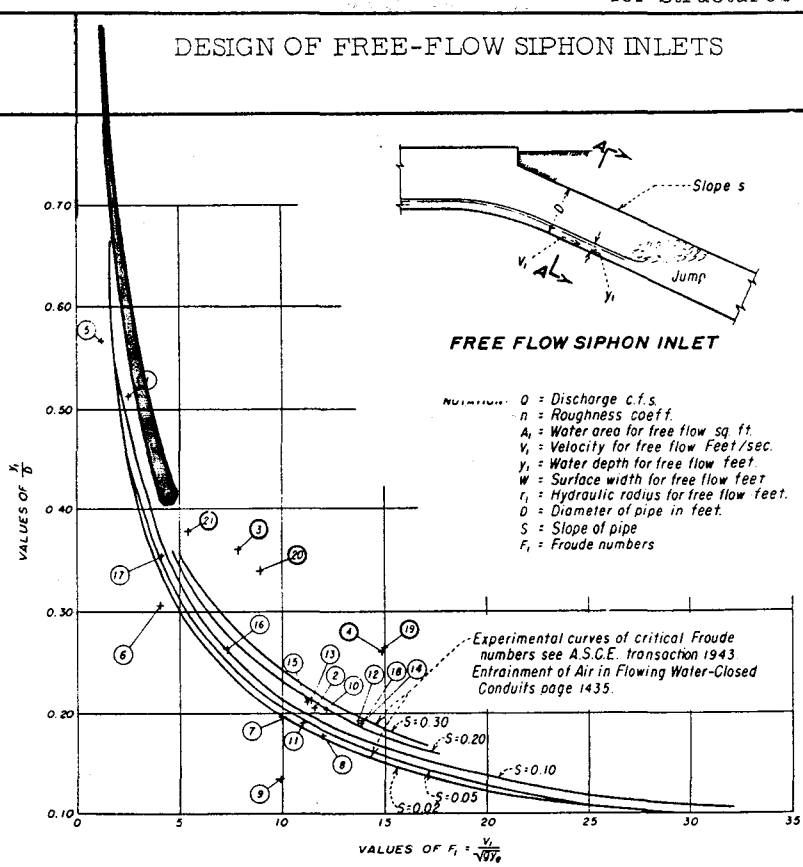
Time Max	Time Min	Line	XL	RH Max	DH Max	H Max	RH Min	DH Min	H Min
.000	.000	1	.000	1.000	.000	1735.000	1.000	.000	1735.000
4.161	2.214	1	1.000	1.001	2.230	1736.138	.999	-.179	1733.728
4.161	2.214	2	.000	1.001	2.230	1736.138	.999	-.179	1733.728
4.020	9.732	2	1.000	1.002	19.579	1739.286	.991	-.729	1718.978
4.020	9.732	3	.000	1.002	19.579	1739.286	.991	-.729	1718.978
3.851	9.563	3	1.000	.998	26.068	1731.574	.983	-.532	1704.974
3.851	9.563	4	.000	.998	26.068	1731.574	.983	-.532	1704.974
3.681	9.986	4	1.000	.992	29.108	1720.413	.974	-.633	1690.672
3.681	9.986	5	.000	.992	29.108	1720.413	.974	-.633	1690.672
3.498	9.803	5	1.000	.984	30.797	1707.902	.966	-.382	1676.722
3.498	9.803	6	.000	.984	30.797	1707.902	.966	-.382	1676.722
3.315	1.312	6	1.000	.977	31.859	1694.762	.958	-.123	1662.781
3.315	1.312	7	.000	.977	31.859	1694.762	.958	-.123	1662.781
3.385	1.128	7	1.000	.969	32.151	1680.854	.950	-.047	1648.656
3.385	1.128	8	.000	.969	32.151	1680.854	.950	-.047	1648.656
3.484	1.030	8	1.000	.964	32.179	1673.235	.946	-.094	1640.962
3.484	1.030	9	.000	.964	32.179	1673.235	.946	-.094	1640.962
3.611	.889	9	1.000	.960	32.096	1666.400	.942	-.139	1634.165
3.611	.889	10	.000	.960	32.096	1666.400	.942	-.139	1634.165
3.300	.719	10	1.000	.955	31.924	1657.225	.937	-.229	1625.072
3.300	.719	11	.000	.955	31.924	1657.225	.937	-.229	1625.072
3.329	.691	11	1.000	.954	31.904	1655.705	.936	-.243	1623.557
3.329	.691	12	.000	.954	31.904	1655.705	.936	-.243	1623.557
3.427	.578	12	1.000	.952	31.748	1651.420	.933	-.277	1619.395
3.427	.578	13	.000	.952	31.748	1651.420	.933	-.277	1619.395
3.568	.395	13	1.000	.948	31.078	1644.558	.930	-.348	1613.132
3.568	.395	14	.000	.948	31.078	1644.558	.930	-.348	1613.132
3.865	.099	14	1.000	.941	30.312	1633.472	.924	-.422	1602.737
3.865	.099	15	.000	.941	30.312	1633.472	.924	-.422	1602.737
4.401	.056	15	1.000	.940	30.131	1631.743	.923	-.442	1601.169
4.401	.056	16	.000	.940	30.131	1631.743	.923	-.442	1601.169
4.401	.042	16	1.000	.940	30.033	1631.128	.923	-.449	1600.647
.014	6.347	17	.000	.921	.243	1598.759	.920	-1.780	1596.736
.000	.000	17	1.000	.921	.000	1598.000	.921	.000	1598.000

APPENDIX E

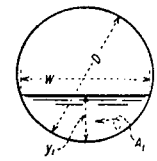
USBR--SIPHON INLET DESIGN CURVES

DESIGN OF FREE-FLOW SIPHON INLETS

Fig. 12 Par. 2.25B



FREE FLOW SIPHON INLET



SECTION A–A

NOTATION
- Q = Discharge c.f.s.
- n = Roughness coeff.
- A_1 = Water area for free flow sq. ft.
- V_1 = Velocity for free flow Feet/sec.
- y_1 = Water depth for free flow feet.
- W = Surface width for free flow feet.
- r_1 = Hydraulic radius for free flow feet.
- D = Diameter of pipe in feet.
- S = Slope of pipe
- F_1 = Froude numbers

	LOCATION	TYPE OF PIPE	Q	D	n	s	$\frac{y_1}{D}$	F_1
1	Yakima River – Yakima Project	Conc.	925	111"	.010	.82	.511	2.47
2	Malheur River – Owyhee Project	Steel	325	80"	.010	.213	.205	11.60
(3)	Basin Siphon – King Hill	Wood	250	57"	.012	.17	.360	7.90
(4)	Basin Siphon – King Hill	Conc	250	54"	.012	.61	.260	14.90
5	San Diego Sta 620+00 N	Conc.	95	54"	.010	.0033	.567	1.25
6	San Diego Sta 961+00 N	Conc	95	54"	.010	.029	.305	4.10
7	San Diego Sta 1146+00 N	Conc.	95	54"	.010	.19	.194	10.0
8	San Diego Sta. 1545+15 N	Conc	95	54"	.010	.2716	.177	11.90
9	San Diego Sta. 1817+50 N	Conc.	95	72"	.010	.1935	.134	9.95
10	San Diego Sta 1873+50 N	Conc	95	48"	.010	.3053	.202	12.15
11	San Diego Sta. 2200+02 N	Conc	95	54"	.010	.2198	.185	10.95
12	San Diego Sta 1303+56 S	Conc	95	48"	.010	.3643	.192	13.70
13	San Diego Sta 1217+50 S	Conc	95	48"	.010	.2563	.212	11.35
14	San Diego Sta 1073+00 S	Conc.	95	48"	.010	.3714	.19	13.83
15	San Diego Sta 1073+00 S	Conc	95	48"	.012	.3714	.211	11.20
16	San Diego Sta 419+00 S	Conc	95	48"	.010	.104	.262	7.33
17	San Diego Sta 171+96 S	Conc	95	48"	.010	.0336	.355	4.17
18	San Diego Sta 79+92 S	Conc	95	48"	.010	.377	.190	13.80
(19)	High Mesa – Uncompaghre	Steel	42	26"	.010	.535	.264	15.00
(20)	Lake Valley Crossing P.G.E	Steel	35	24"	.013	.367	.349	8.95
(21)	Lake Valley Crossing P.G.E	Steel	25	24"	.016	.208	.378	5.43

NOTES

Siphon inlets marked thus ◯, have given trouble in operation and air outlets were installed in some cases to relieve the blowing back of air and water.

All other siphons have not given trouble in operation.

Study made indicates that free flow siphon inlets designed so that Froude number will not fall above the critical curves established by experiments will give satisfactory performance.

Proceedure to determine Froude number.

For a given Q, diameter D, slope s and coeff n, proceed as follows:

a. Calculate V_1 with Manning's Formula.
b. Calculate y_1
c. Calculate $W = 2\sqrt{(D-y_1)y_1}$
d. Calculate $y_e = \frac{A_1}{W}$
e. Calculate Froude number $F_1 = \frac{V_1}{\sqrt{g y_e}}$

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

DESIGN OF FREE FLOW SIPHON INLETS

DRAWN J.W.F. SUBMITTED R. Seiler
TRACED E.P.S. RECOMMENDED
CHECKED E.S. APPROVED

REV. 3-29-62
REV. 5-8-52

DENVER, COLORADO, FEB. 1, 1949 | 103-D-1

APPENDIX F

PROGRAM PCWTH OUTPUT
25% FLOW BLOCKAGE WITH AIR VENTS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5'x 25' OVERFLOW VENTS
17RESERVOR

6	2	1	1			
6	3	1	13			
6	4	1	13			
6	5	1	13			
6	6	1	13			
6	7	1	13			
6	8	1	13			
1	9	1	7			
6	10	1	9			
6	11	1	12			
1	12	1	2			
6	13	1	8			
6	14	1	12			
1	15	1	20			
6	16	1	3			
7	17	1	1			
2	0	0	1			
0.0000000	20.0	120.00	1735.000	1735.000	1431.000	1
3500.	9.0000	50.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	650.0	0.025000	1431.000	.999000	
3500.	9.0000	350.0	0.025000	1431.000	.999000	
3500.	9.5000	450.0	0.022500	1431.000	.999000	
3500.	9.5000	600.0	0.022500	1431.000	.999000	
3500.	9.5000	100.0	0.022500	1431.000	.999000	
3500.	10.0000	400.0	0.020000	1431.000	.999000	
3500.	10.0000	600.0	0.020000	1431.000	.999000	
3500.	10.0000	1000.0	0.020000	1431.000	.999000	
3500.	10.0000	150.0	0.020000	1431.000	.999000	
3500.	10.0000	50.0	0.020000	1431.000	.999000	
3500.	10.0000	50.0	0.020000	1431.000	.999000	
10.00	1733.908	12.62				
10.00	1719.707	12.62				
10.00	1705.506	12.62				
10.00	1691.305	12.62				
10.00	1677.104	12.62				
10.00	1662.904	12.62				
10.00	1648.703	12.62				
10.00	1634.304	12.62				
10.00	1625.301	12.62				
10.00	1619.672	12.62				
10.00	1613.480	12.62				
10.00	1601.611	12.62				
0.0	1595.000	3				
0.0	677500.0					
2.0	508125.0					
200.0	508125.0					

Program PCWTH Version 3.0 (1990)

Date: 4-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5'x 25' OVERFLOW VENTS

PIPE LINE DATA

Number	Dia	Celerity	Length	Flow(cfs)	Darcy F	DXPRT	DWS	Tank Dia	NBOUND	NBR	NO	NX
1	9.00	3500.0	50.0	1431.00	.025	.999	1733.91	12.62	6	2	1	1
2	9.00	3500.0	650.0	1431.00	.025	.999	1719.71	12.62	6	3	1	13
3	9.00	3500.0	650.0	1431.00	.025	.999	1705.51	12.62	6	4	1	13
4	9.00	3500.0	650.0	1431.00	.025	.999	1691.31	12.62	6	5	1	13
5	9.00	3500.0	650.0	1431.00	.025	.999	1677.10	12.62	6	6	1	13
6	9.00	3500.0	650.0	1431.00	.025	.999	1662.90	12.62	6	7	1	13
7	9.00	3500.0	650.0	1431.00	.025	.999	1648.70	12.62	6	8	1	13
8	9.00	3500.0	350.0	1431.00	.025	.999	.00	.00	1	9	1	7
9	9.50	3500.0	450.0	1431.00	.023	.999	1634.30	12.62	6	10	1	9
10	9.50	3500.0	600.0	1431.00	.023	.999	1625.30	12.62	6	11	1	12
11	9.50	3500.0	100.0	1431.00	.023	.999	.00	.00	1	12	1	2
12	10.00	3500.0	400.0	1431.00	.020	.999	1619.67	12.62	6	13	1	8
13	10.00	3500.0	600.0	1431.00	.020	.999	1613.48	12.62	6	14	1	12
14	10.00	3500.0	1000.0	1431.00	.020	.999	.00	.00	1	15	1	20
15	10.00	3500.0	150.0	1431.00	.020	.999	1601.61	12.62	6	16	1	3
16	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	7	17	1	1
17	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	2	0	0	1

Program PCWTH Version 3.0 (1990)

Date: 4-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5'x 25' OVERFLOW VENTS

STEADY STATE ANALYSIS

Time	Line	XL	H Ratio	H Change	Head	Q Ratio	Q Change	Flow	H Tank or CV	ALPHA	BETA
.000	1	.000	1.000	.000	1735.000	1.000	.000	1431.000	.000	.000	.000
.000	1	1.000	.999	.000	1733.908	1.000	.000	1431.000	1733.908		
.000	2	.000	.999	.000	1733.908	1.000	.000	1431.000	.000		
.000	2	1.000	.991	.000	1719.707	1.000	.000	1431.000	1719.707		
.000	3	.000	.991	.000	1719.707	1.000	.000	1431.000	.000		
.000	3	1.000	.983	.000	1705.506	1.000	.000	1431.000	1705.506		
.000	4	.000	.983	.000	1705.506	1.000	.000	1431.000	.000		
.000	4	1.000	.975	.000	1691.305	1.000	.000	1431.000	1691.305		
.000	5	.000	.975	.000	1691.305	1.000	.000	1431.000	.000		
.000	5	1.000	.967	.000	1677.104	1.000	.000	1431.000	1677.104		
.000	6	.000	.967	.000	1677.104	1.000	.000	1431.000	.000		
.000	6	1.000	.958	.000	1662.904	1.000	.000	1431.000	1662.904		
.000	7	.000	.958	.000	1662.904	1.000	.000	1431.000	.000		
.000	7	1.000	.950	.000	1648.703	1.000	.000	1431.000	1648.703		
.000	8	.000	.950	.000	1648.703	1.000	.000	1431.000	.000		
.000	8	1.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	1.000	.942	.000	1634.304	1.000	.000	1431.000	1634.304		
.000	10	.000	.942	.000	1634.304	1.000	.000	1431.000	.000		
.000	10	1.000	.937	.000	1625.301	1.000	.000	1431.000	1625.301		
.000	11	.000	.937	.000	1625.301	1.000	.000	1431.000	.000		
.000	11	1.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	1.000	.934	.000	1619.672	1.000	.000	1431.000	1619.672		
.000	13	.000	.934	.000	1619.672	1.000	.000	1431.000	.000		
.000	13	1.000	.930	.000	1613.480	1.000	.000	1431.000	1613.480		
.000	14	.000	.930	.000	1613.480	1.000	.000	1431.000	.000		
.000	14	1.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	1.000	.923	.000	1601.611	1.000	.000	1431.000	1601.611		
.000	16	.000	.923	.000	1601.611	1.000	.000	1431.000	677500.000		
.000	16	1.000	.923	.000	1601.095	1.000	.000	1431.000	.000		
.000	17	.000	.921	.000	1598.516	1.000	.000	1431.000	.000		
.000	17	1.000	.921	.000	1598.000	1.000	.000	1431.000	.000		

Program PCWTH Version 3.0 (1990)

Date: 4-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5'x 25' OVERFLOW VENTS

FINAL RESULTS OF ANALYSIS

Time Max	Time Min	Line	XL	RH Max	DH Max	H Max	RH Min	DH Min	H Min
.000	.000	1	.000	1.000	.000	1735.000	1.000	.000	1735.000
79.690	6.432	1	1.000	.999	.015	1733.923	.999	.000	1733.907
79.690	6.432	2	.000	.999	.015	1733.923	.999	.000	1733.907
79.676	.000	2	1.000	.991	.211	1719.918	.991	.000	1719.707
79.676	.000	3	.000	.991	.211	1719.918	.991	.000	1719.707
77.800	.000	3	1.000	.983	.340	1705.846	.983	.000	1705.506
77.800	.000	4	.000	.983	.340	1705.846	.983	.000	1705.506
90.438	.014	4	1.000	.975	.465	1691.770	.975	.000	1691.305
90.438	.014	5	.000	.975	.465	1691.770	.975	.000	1691.305
87.419	.014	5	1.000	.967	.578	1677.683	.967	.000	1677.104
87.419	.014	6	.000	.967	.578	1677.683	.967	.000	1677.104
96.996	.000	6	1.000	.959	.681	1663.585	.958	.000	1662.904
96.996	.000	7	.000	.959	.681	1663.585	.958	.000	1662.904
106.178	.000	7	1.000	.951	.778	1649.481	.950	.000	1648.703
106.178	.000	8	.000	.951	.778	1649.481	.950	.000	1648.703
106.376	.353	8	1.000	.946	.835	1641.891	.946	-.039	1641.017
106.376	.353	9	.000	.946	.835	1641.891	.946	-.039	1641.017
106.319	.000	9	1.000	.942	.885	1635.188	.942	.000	1634.304
106.319	.000	10	.000	.942	.885	1635.188	.942	.000	1634.304
100.029	.000	10	1.000	.937	.943	1626.244	.937	.000	1625.301
100.029	.000	11	.000	.937	.943	1626.244	.937	.000	1625.301
117.024	.818	11	1.000	.936	.951	1624.751	.936	-.007	1623.793
117.024	.818	12	.000	.936	.951	1624.751	.936	-.007	1623.793
110.649	.014	12	1.000	.934	.980	1620.652	.934	.000	1619.672
110.649	.014	13	.000	.934	.980	1620.652	.934	.000	1619.672
83.005	2.821	13	1.000	.931	1.014	1614.494	.930	.000	1613.480
83.005	2.821	14	.000	.931	1.014	1614.494	.930	.000	1613.480
8.632	1.255	14	1.000	.925	1.421	1604.581	.924	-.039	1603.120
8.632	1.255	15	.000	.925	1.421	1604.581	.924	-.039	1603.120
8.364	1.481	15	1.000	.924	1.603	1603.214	.923	-.038	1601.573
8.364	1.481	16	.000	.924	1.603	1603.214	.923	-.038	1601.573
8.858	.014	16	1.000	.924	1.339	1602.434	.923	-.245	1600.850
7.800	2.003	17	.000	.921	.283	1598.799	.921	-.536	1597.980
.000	.000	17	1.000	.921	.000	1598.000	.921	.000	1598.000

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5' DIA. OVERFLOW VENTS

```
17RESERVOR
         6         2         1         1
         6         3         1        13
         6         4         1        13
         6         5         1        13
         6         6         1        13
         6         7         1        13
         6         8         1        13
         1         9         1         7
         6        10         1         9
         6        11         1        12
         1        12         1         2
         6        13         1         8
         6        14         1        12
         1        15         1        20
         6        16         1         3
         7        17         1         1
         2         0         0         1
 0.0000000      20.0     80.00  1735.000  1735.000  1431.000         1
     3500.    9.0000      50.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     650.0  0.025000  1431.000   .999000
     3500.    9.0000     350.0  0.025000  1431.000   .999000
     3500.    9.5000     450.0  0.022500  1431.000   .999000
     3500.    9.5000     600.0  0.022500  1431.000   .999000
     3500.    9.5000     100.0  0.022500  1431.000   .999000
     3500.   10.0000     400.0  0.020000  1431.000   .999000
     3500.   10.0000     600.0  0.020000  1431.000   .999000
     3500.   10.0000    1000.0  0.020000  1431.000   .999000
     3500.   10.0000     150.0  0.020000  1431.000   .999000
     3500.   10.0000      50.0  0.020000  1431.000   .999000
     3500.   10.0000      50.0  0.020000  1431.000   .999000
     10.00  1733.908     12.62
     10.00  1719.707      5.00
     10.00  1705.506      5.00
     10.00  1691.305      5.00
     10.00  1677.104      5.00
     10.00  1662.904      5.00
     10.00  1648.703      5.00
     10.00  1634.304      5.00
     10.00  1625.301      5.00
     10.00  1619.672      5.00
     10.00  1613.480      5.00
     10.00  1601.611     12.62
       0.0  1595.000         3
       0.0  677500.0
       2.0  508125.0
     200.0  508125.0
```

Program PCWTH Version 3.0 (1990)
TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

Date: 4-01-98

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5' DIA. OVERFLOW VENTS

PIPE LINE DATA

Number	Dia	Celerity	Length	Flow(cfs)	Darcy F	DXPRT	DWS	Tank Dia	NBOUND	NBR	NO	NX
1	9.00	3500.0	50.0	1431.00	.025	.999	1733.91	12.62	6	2	1	1
2	9.00	3500.0	650.0	1431.00	.025	.999	1719.71	5.00	6	3	1	13
3	9.00	3500.0	650.0	1431.00	.025	.999	1705.51	5.00	6	4	1	13
4	9.00	3500.0	650.0	1431.00	.025	.999	1691.31	5.00	6	5	1	13
5	9.00	3500.0	650.0	1431.00	.025	.999	1677.10	5.00	6	6	1	13
6	9.00	3500.0	650.0	1431.00	.025	.999	1662.90	5.00	6	7	1	13
7	9.00	3500.0	650.0	1431.00	.025	.999	1648.70	5.00	6	8	1	13
8	9.00	3500.0	350.0	1431.00	.025	.999	.00	.00	1	9	1	7
9	9.50	3500.0	450.0	1431.00	.023	.999	1634.30	5.00	6	10	1	9
10	9.50	3500.0	600.0	1431.00	.023	.999	1625.30	5.00	6	11	1	12
11	9.50	3500.0	100.0	1431.00	.023	.999	.00	.00	1	12	1	2
12	10.00	3500.0	400.0	1431.00	.020	.999	1619.67	5.00	6	13	1	8
13	10.00	3500.0	600.0	1431.00	.020	.999	1613.48	5.00	6	14	1	12
14	10.00	3500.0	1000.0	1431.00	.020	.999	.00	.00	1	15	1	20
15	10.00	3500.0	150.0	1431.00	.020	.999	1601.61	12.62	6	16	1	3
16	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	7	17	1	1
17	10.00	3500.0	50.0	1431.00	.020	.999	.00	.00	2	0	0	1

Program PCWTH Version 3.0 (1990)

Date: 4-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5' DIA. OVERFLOW VENTS

STEADY STATE ANALYSIS

Time	Line	XL	H Ratio	H Change	Head	Q Ratio	Q Change	Flow	H Tank or CV	ALPHA	BETA
.000	1	.000	1.000	.000	1735.000	1.000	.000	1431.000	.000	.000	.000
.000	1	1.000	.999	.000	1733.908	1.000	.000	1431.000	1733.908		
.000	2	.000	.999	.000	1733.908	1.000	.000	1431.000	.000		
.000	2	1.000	.991	.000	1719.707	1.000	.000	1431.000	1719.707		
.000	3	.000	.991	.000	1719.707	1.000	.000	1431.000	.000		
.000	3	1.000	.983	.000	1705.506	1.000	.000	1431.000	1705.506		
.000	4	.000	.983	.000	1705.506	1.000	.000	1431.000	.000		
.000	4	1.000	.975	.000	1691.305	1.000	.000	1431.000	1691.305		
.000	5	.000	.975	.000	1691.305	1.000	.000	1431.000	.000		
.000	5	1.000	.967	.000	1677.104	1.000	.000	1431.000	1677.104		
.000	6	.000	.967	.000	1677.104	1.000	.000	1431.000	.000		
.000	6	1.000	.958	.000	1662.904	1.000	.000	1431.000	1662.904		
.000	7	.000	.958	.000	1662.904	1.000	.000	1431.000	.000		
.000	7	1.000	.950	.000	1648.703	1.000	.000	1431.000	1648.703		
.000	8	.000	.950	.000	1648.703	1.000	.000	1431.000	.000		
.000	8	1.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	.000	.946	.000	1641.056	1.000	.000	1431.000	.000		
.000	9	1.000	.942	.000	1634.304	1.000	.000	1431.000	1634.304		
.000	10	.000	.942	.000	1634.304	1.000	.000	1431.000	.000		
.000	10	1.000	.937	.000	1625.301	1.000	.000	1431.000	1625.301		
.000	11	.000	.937	.000	1625.301	1.000	.000	1431.000	.000		
.000	11	1.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	.000	.936	.000	1623.800	1.000	.000	1431.000	.000		
.000	12	1.000	.934	.000	1619.672	1.000	.000	1431.000	1619.672		
.000	13	.000	.934	.000	1619.672	1.000	.000	1431.000	.000		
.000	13	1.000	.930	.000	1613.480	1.000	.000	1431.000	1613.480		
.000	14	.000	.930	.000	1613.480	1.000	.000	1431.000	.000		
.000	14	1.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	.000	.924	.000	1603.159	1.000	.000	1431.000	.000		
.000	15	1.000	.923	.000	1601.611	1.000	.000	1431.000	1601.611		
.000	16	.000	.923	.000	1601.611	1.000	.000	1431.000	677500.000		
.000	16	1.000	.923	.000	1601.095	1.000	.000	1431.000	.000		
.000	17	.000	.921	.000	1598.516	1.000	.000	1431.000	.000		
.000	17	1.000	.921	.000	1598.000	1.000	.000	1431.000	.000		

Program PCWTH Version 3.0 (1990)

Date: 4-01-98

TRANSIENT FLOW ANALYSIS FOR CLOSED CONDUITS

PIMA ROAD THREE BASINS PROJECT -- CAST-IN-PLACE PIPELINES FOR STORM FLOWS
SURGE ANALYSIS FOR 25% FLOW BLOCKAGE WITH 5' DIA. OVERFLOW VENTS

FINAL RESULTS OF ANALYSIS

Time Max	Time Min	Line	XL	RH Max	DH Max	H Max	RH Min	DH Min	H Min
.000	.000	1	.000	1.000	.000	1735.000	1.000	.000	1735.000
48.914	42.736	1	1.000	.999	.053	1733.961	.999	-.036	1733.872
48.914	42.736	2	.000	.999	.053	1733.961	.999	-.036	1733.872
34.006	41.721	2	1.000	.992	.570	1720.277	.991	-.120	1719.587
34.006	41.721	3	.000	.992	.570	1720.277	.991	-.120	1719.587
32.624	.000	3	1.000	.983	.846	1706.352	.983	.000	1705.506
32.624	.000	4	.000	.983	.846	1706.352	.983	.000	1705.506
30.296	.014	4	1.000	.975	.953	1692.258	.975	.000	1691.305
30.296	.014	5	.000	.975	.953	1692.258	.975	.000	1691.305
27.602	.014	5	1.000	.967	1.029	1678.134	.967	.000	1677.104
27.602	.014	6	.000	.967	1.029	1678.134	.967	.000	1677.104
24.852	.000	6	1.000	.959	1.109	1664.013	.958	.000	1662.904
24.852	.000	7	.000	.959	1.109	1664.013	.958	.000	1662.904
22.102	.000	7	1.000	.951	1.192	1649.894	.950	.000	1648.703
22.102	.000	8	.000	.951	1.192	1649.894	.950	.000	1648.703
20.790	.353	8	1.000	.947	1.186	1642.242	.946	-.038	1641.018
20.790	.353	9	.000	.947	1.186	1642.242	.946	-.038	1641.018
18.999	.000	9	1.000	.943	1.314	1635.618	.942	.000	1634.304
18.999	.000	10	.000	.943	1.314	1635.618	.942	.000	1634.304
16.742	.000	10	1.000	.938	1.276	1626.576	.937	.000	1625.301
16.742	.000	11	.000	.938	1.276	1626.576	.937	.000	1625.301
16.587	.254	11	1.000	.937	1.253	1625.054	.936	-.007	1623.794
16.587	.254	12	.000	.937	1.253	1625.054	.936	-.007	1623.794
14.739	.014	12	1.000	.934	1.221	1620.893	.934	.000	1619.672
14.739	.014	13	.000	.934	1.221	1620.893	.934	.000	1619.672
12.017	2.793	13	1.000	.931	1.247	1614.726	.930	-.002	1613.478
12.017	2.793	14	.000	.931	1.247	1614.726	.930	-.002	1613.478
8.702	1.255	14	1.000	.925	1.522	1604.681	.924	-.039	1603.120
8.702	1.255	15	.000	.925	1.522	1604.681	.924	-.039	1603.120
8.463	1.481	15	1.000	.924	1.622	1603.233	.923	-.038	1601.573
8.463	1.481	16	.000	.924	1.622	1603.233	.923	-.038	1601.573
8.999	.014	16	1.000	.924	1.354	1602.449	.923	-.245	1600.850
7.870	2.003	17	.000	.922	.289	1598.805	.921	-.536	1597.980
.000	.000	17	1.000	.921	.000	1598.000	.921	.000	1598.000

APPENDIX G

SUMMARY TABLE AND GRAPH FOR OVERFLOW VENT STRUCTURES

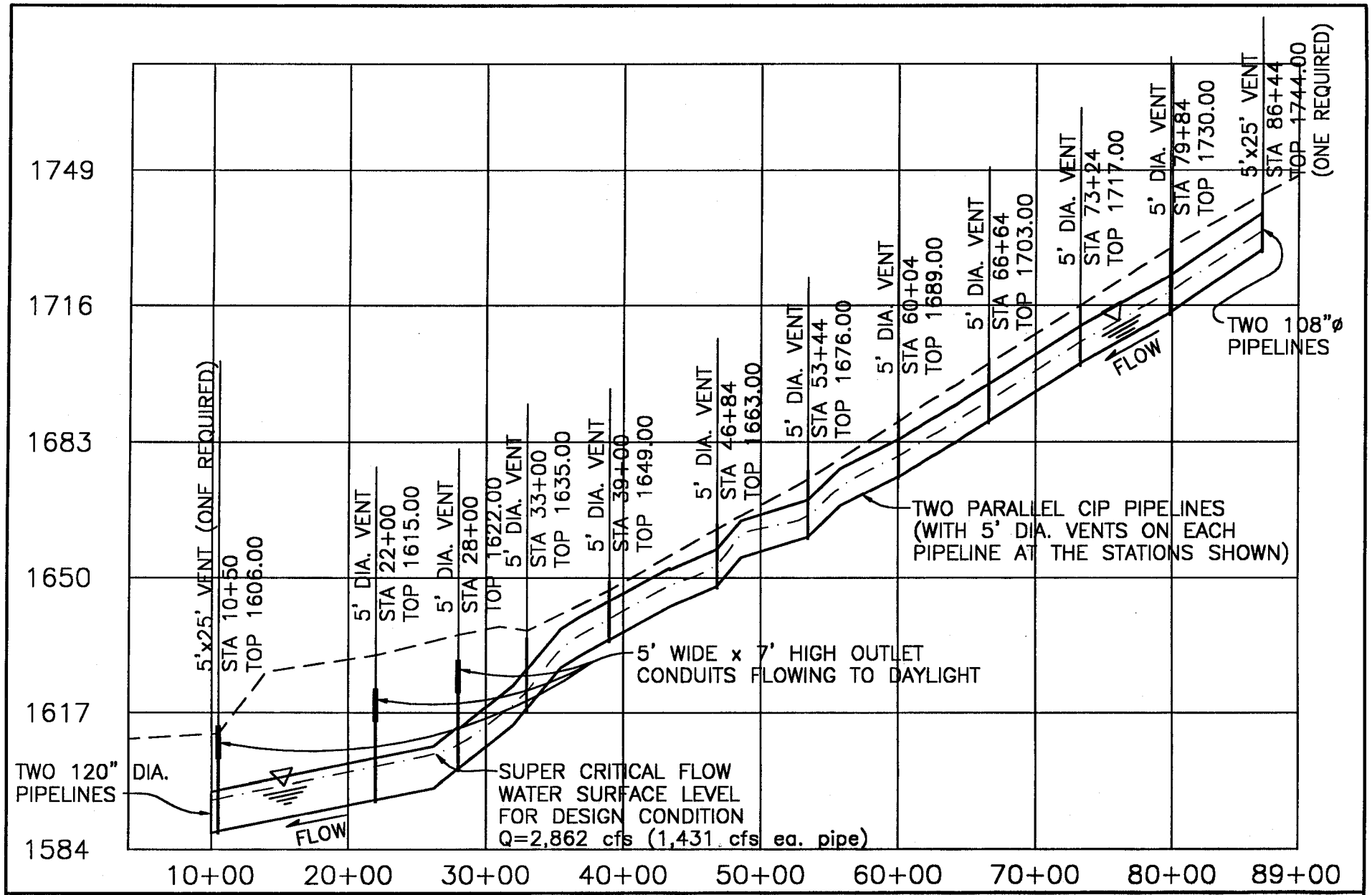
PIMA ROAD THREE BASINS PROJECT

OVERFLOW VENT STRUCTURES

PRELIMINARY DESIGN DATA

April 1, 1998

Proposed Vent Station	Pipe Length Between Vents	Vent Top Elevation	Change in Elevation	Overflow Vent Size
10+50		1606		5' x 25' Vent
	1150'		9'	(with 5' wide x 7' outlet)
22+00		1615		5' Dia. Vent
	600'		7'	(with 5' wide x 7' outlet)
28+00		1622		5' Dia. Vent
	500'		13'	(with 5' wide x 7' outlet)
33+00		1635		5' Dia. Vent
	600'		14'	(on each pipeline)
39+00		1649		5' Dia. Vent
	784'		14'	(on each pipeline)
46+84		1663		5' Dia. Vent
	660'		13'	(on each pipeline)
53+44		1676		5' Dia. Vent
	660'		13'	(on each pipeline)
60+04		1689		5' Dia. Vent
	660'		14'	(on each pipeline)
66+64		1703		5' Dia. Vent
	660'		14'	(on each pipeline)
73+24		1717		5' Dia. Vent
	660'		13'	(on each pipeline)
79+84		1730		5' Dia. Vent
	660'		14'	(on each pipeline)
86+44		1744		5' x 25' Vent



FUTURE ENGINEERING TECHNOLOGY GROUP

2365 LOG ROAD CALHAN, COLORADO 80808

PIMA ROAD THREE BASINS PROJECT

OVERFLOW VENT STRUCTURES

DESIGNED BY DB	SCALE	DATE ISSUED: 04/04/98	
DRAWN BY MJP	HORIZ. 1"=1000'	SHEET NO. 1 OF 1 SHEETS	
CHECKED BY DB	VERT. 1"=33'		

Appendix E

Cast-In-Place Earth Reinforced Concrete Pipe
Alternative Storm Drain System
by Curtiss W. Gilley, PE

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE ALTERNATIVE STORM DRAIN SYSTEM

City of Scottsdale Desert Greenbelt
PIMA ROAD THREE BASINS (PR3B) PROJECT
Hydraulic and Structural Analysis

FOR

STANTEC CONSULTING, INC.
7776 Pointe Parkway W. Suite 290
Phoenix AZ 85044

BY

TERRAIN ENGINEERING, INC.
25740 WASHINGTON AVENUE
MURRIETA, CA 92562
TELEPHONE: (909) 698-8471
FAX: (909 698-7898)

Registered Professional Engineer (Civil)
CERTIFICATE NO.
25868
CURTISS W
GILLEY
Date Signed 1/14/99
ARIZONA, U.S.A.

TABLE OF CONTENTS

1. SITE EVALUATION, STRUCTURAL ANALYSIS AND CALCULATIONS

2. HYDRAULIC EVALUATION, ANALYSIS AND CALCULATIONS

3. PUBLISHED PAPERS ON CAST-IN-PLACE CONCRETE PIPE PERFORMANCE

4 CONCLUSIONS AND LIMITATIONS

Site Evaluation, Structural Analysis and Calculations for use of Cast-In-Place Earth Reinforced Concrete Pipe

This firm has completed a site evaluation and structural analysis for the use of cast-in-place earth reinforced concrete pipe as an alternative to the conventional use of reinforced concrete pipe. This report presents the results of the site evaluation and structural analysis.

The soil conditions in the project area from construction experience in this area and from a comprehensive review of " Geotechnical Investigation Report, Desert Greenbelt Phase I Channels, Pima Road & Cap Canal, Scottsdale , Arizona prepared by Agra Earth & Environmental, Inc., August 25, 1995, are very suitable for the construction of cast-in-place concrete pipe. Specifically, within the pipe zone area thy are described as " very firm to hard interbedded layers of silty to clayey sands and silty sands with gravel". The soil test data indicate that the project area soils are capable of providing the lateral support required for the construction of cast-in-place earth reinforced concrete pipe. Should an area be encountered where there is a deficiency in the cementitious or cohesive properties of the soil where the trench walls in the pipe zone will not stand vertical, over excavation and recompaction to 90% maximum dry density will have to be accomplished.

A cast-in-place earth reinforced concrete pipe system is constructed as a continuous single-stage monolithic casting in a round bottom trench excavated to the design outer diameter of the pipe. The trench is actually a trench form for a self propelled casting machine to slip form the pipe directly in the trench "neat" to the excavated trench wall and invert. This is in contrast to a reinforced concrete pipe system which is constructed by placing factory manufactured pipe in an excavated trench with bedding and placement of compacted backfill material around and over the pipe.

Cast-in-Place Earth Reinforced Concrete Pipe is a soil structure interaction dependent product that relies upon competent soils for the development of the lateral force field needed to contain the maximum tensile stress in the pipe ring to that which is safely less than that of the rupture stress of the concrete. This is in contrast to steel reinforced concrete pipe where reinforcing steel in the pipe ring is utilized with compacted bedding to provide the force field necessary to keep the tensile stresses in the pipe ring from exceeding the allowable design stresses

The analysis of earth reinforced cast-in-place concrete pipe falls in the category of small deflection theory. The structural computational program employs classical principles of two dimensional plane strain utilizing Roark's Formulas for Stress and Strain (6th Edition by Warren C, Young, 1989, Circular rings and arches, Chapter8.) The structural analysis program used is CAPLCOP ST 1.04.

These calculations are prepared on the worst case situations where imposition of the most severe loadings are used to obtain the highest stresses within the pipe. A structural analysis supporting the use of Cast-In-Place Earth Reinforced Concrete Pipe (CIPCP) as an alternative to the reinforced concrete pipe (RCP) specified for the storm drain system for the subject project has been performed.

The vertical loading applied is a combination of Marston earth load with HS2O AASHTO live loading. AASHTO live load impact is included where the cover is 3' or less. Th actual live load applied is a 16,000 lb. wheel load taken as a point load (more conservative than the AASHTO footprint load) spread to the pipe at 7H:8V. The dead weight of the pipe is included. The stress calculations are made with the pipe empty and full of water. Hydrostatic loading is included where the hydraulic grade line is above the pipe soffit.

The lateral loading applied, which provides the counter moments to resist the moments resulting from the vertical load, relies upon the principles of soil structure interaction since the pipe is cast in a trench having vertical side walls and an invert area shaped to the pipe outside diameter (earth reinforcement). For CIPCP, the vertical loading pushing downward causes the pipe to deflect outward to the trench walls (structure pushes to soil, passive movement). This passive movement activates the passive pressure characteristic of the soil, Kp.

Rankine theory for the development of the lateral pressure coefficient depends on the soil angle of internal friction ϕ. This value for CIPCP varies from a lower limit, $Kp = 1 - \sin \phi$, "at rest", to an upper limit of $Kp = 1 + \sin \phi / 1 - \sin \phi$. The amount of the available lateral force activated depends on the ratio of anticipated wall movement to wall height and the internal angle of friction of the soil. The better the soil the less movement required to activate higher lateral resisting forces (reference the enclosed figure, Relationship between wall movement and earth pressure, Clough, G.W., and Ducan, J.M.1991. Earth Pressures. Foundation Engineering Handbook, ed. H-Y Fang, pp 224-235). The referenced Geotechnical report indicates angles of internal friction of up to 56 degrees. For conservatism, the angle of internal friction used to determine the passive pressure coefficients utilized in the stress calculations in this report is 30 degrees. For this CIPCP design, a

pressure coefficient Kp of 0.5 to 2.2 is used. This upper value is based on amount of lateral pressure needed to keep the stresses in the pipe ring to those which the concrete can sustain. The maximum upper limit is the full passive pressure Kp = 3.0. These conservative Kp for lateral pressure combined with the selection of an appropriate concrete strength provide the criteria used to calculate design stresses in the pipe ring.

The program at user selected points pf the pipe's cross-section, determines moments, thrust (ring, compression), and shears. The program queries the user for the following information: nominal diameter, distance from top of crown to top of trench, total fill height, unit weight of the soil, Rankine coefficient of lateral pressure, ultimate strength and modulus of rupture of the concrete, live load, hydrostatic head above crown (if full), and the number of points of the cross-section, between crown and invert, the user wishes to have analyzed. Usually 5 points (45 degrees) is used, but each 5 degrees can be selected which provide 37 points from crown to invert.

The program analyzes the cross-section for linear (Rankine) lateral loads from outer invert to top of haunch, (a more conservative loading than from top of pipe) and for horizontal distribution of vertical loads at crown and invert. The output are the stresses, and the associated factors of safety at the inner and outer pipe surface at the user selected points. For this analysis, the stresses and associated factors of safety are computed at 5 points from crown (0 degrees) to invert (180 degrees.)

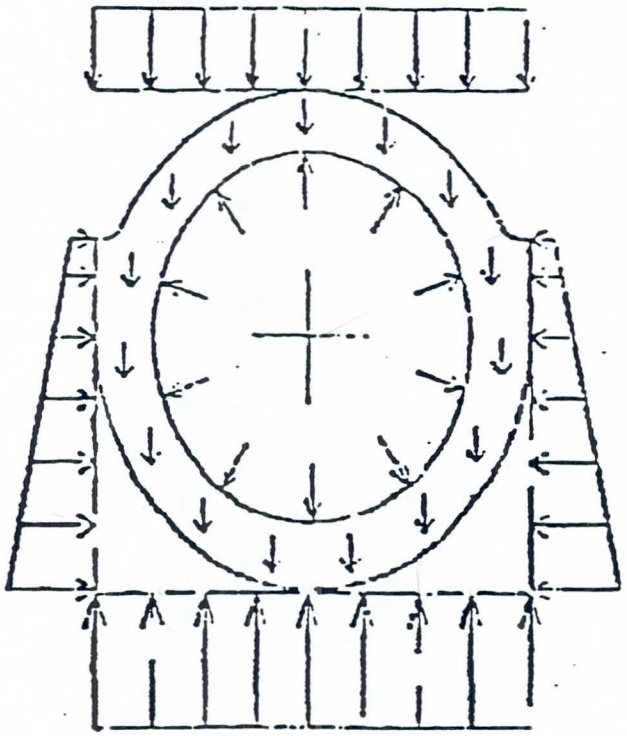
For these design situations, the stresses are measured against the modulus of rupture of 3000 psi compressive strength concrete to obtain a safety factor. The minimum recommended safety factor is 1.5. The analysis show minimum safety factors that exceed 1.5.As an additional safety factor, the soil is capable of providing for more support than that used in these calculations, i.e., Rankine of 0.5 to 1.2 with a maximum of 3.0. The following table summarizes the design situations and stresses. When reviewing these design situations, note that the 108"dia. pipe requires 3 ft.of cover to carry a full 16000 lb. AASHTO live load. The design minimum cover of 1 ft.+/- will only handle live loads including impact of 5000 lb. +/-. In actuality, the pipe will carry the load, but the calculations will not support it.

PIPE DIA.(IN.)	COVER (FT.)	HEAD (FT.)	RANKINE	SAFETY FAC.
120 (A)	4.0	4.0	0.5	1.79
120 (B)	19.0	15.0	0.6	1.62
108 (A)	1.0	0.0	2.2	1.68
108 (B)	10.0	7.5	0.5	1.66
108 (C)	3.0	0.0	0.5	1.54
96	5.0	0.0	0.5	2.07

Construction specifications for Cast-in-Place Concrete Pipe are contained in Arizona Department of Transportation, Standard Specifications. The most recent version in use is a "stored" specification. This is a complete rewrite of the specification contained in the latest printed edition of the ADOT standards. This specification is the recommended specification for construction as it contains the most up to date standards and a defined Quality Assurance Program.

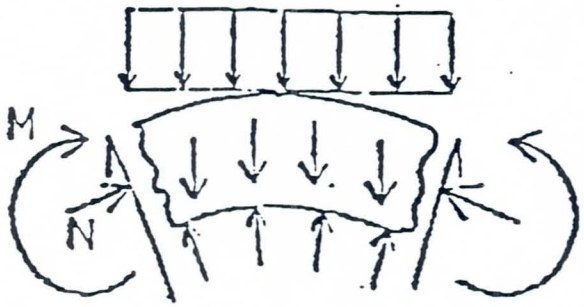
For additional information regarding structural capability of CIPCP, refer to enclosed copies of papers prepared by myself and Lester Gabriel, P.E., Ph.D. The paper entitled "Field Test of 72" Diameter Cast-in-Place Concrete Pipe" was published in the ASCE Journal of Transportation Engineering, January/February 1992. The paper entitled "Field Performance of Structures and Nondestructive Evaluation of Subsurface Infrastructure" was published in the Transportation Research Record, No. 1415, Soils, Geology, and Foundations, Washington, D.C., in 1993.

LOADING DIAGRAM



Not to Scale

Pipe section showing loading and resulting moment, thrust and shear stresses.



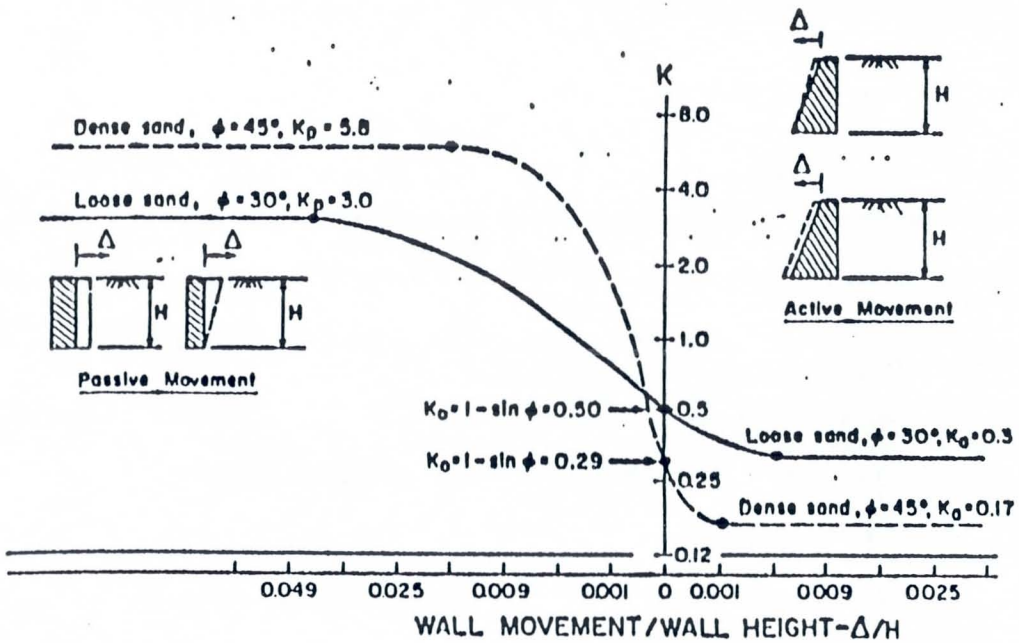


FIGURE 21.2 Relationship between wall movement and earth pressure. (After Clough, G. W. and Duncan, J. M. 1991. Earth Pressures. In *Foundation Engineering Handbook*, ed. H-Y. Fang, pp. 224–235. Van Nostrand Reinhold, New York.)

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA2REV.120A)
LOCATION: SCOTTSDALE, AZ
DATE: 4- 5-1998
TIME: 12:35

PIPE DATA	
NOMINAL DIAMETER (in)=	120
MIN. WALL THICKNESS (in)=	12.0
X-SECT. MIN AREA (in**2)=	4976
MOMENT OF INTERIA (in**4)=	144.0
AREA FOR STRESS CALC (in**2)=	12.0
DISTANCE FROM MID-SEC TO NA (in)=	.2

LIVE LOAD DATA	
DESCRIPTION=	HS20 W/IMPACT
POINT LOAD (LBS)=	16000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	2.3
WIDTH OF UNIFORM LOAD (in)=	84.0

SOIL DATA	
TRENCH HEIGHT (ft)=	3.0
TOTAL COVER HEIGHT (ft)=	4.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	.5
MARSTON LOAD (psi)=	3.5

MISC DATA	
CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	4.0
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA2REV.120A)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	3760	-4064	1555	2456	1946
45.0	-20	-318	142	-13	243
90.0	-3801	4433	-1791	-2482	-2181
135.0	-20	270	-161	-13	-407
180.0	3760	-4897	1990	2456	3259

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-212	11	0	96
45.0	-114	-121	-29	-74	70
90.0	-228	0	-107	-149	34
135.0	-114	-147	-77	-74	112
180.0	0	-326	-10	0	218

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-114	180	-45	97	-55
90.0	0	408	-10	32	-17
135.0	115	450	62	-113	76
180.0	0	0	0	-298	43

PIMA ROAD THREE BASINS (PIMA2REV.120A)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	3705	-201	0
45.0	-211	-340	116
90.0	-3643	-486	428
135.0	74	-415	512
180.0	3307	-337	-298

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-175	17.06	133	3.71
45.0	-18	155.12	-36	81.12
90.0	116	4.25	-187	15.98
135.0	-37	79.33	-31	94.74
180.0	-169	17.63	105	4.68

MINIMUM FACTOR OF SAFETY= 3.71

STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-230	13.01	240	2.05
45.0	-2	974.29	0	5910.82
90.0	233	2.11	-251	11.89
135.0	10	50.19	-17	166.15
180.0	-270	11.07	276	1.79

MINIMUM FACTOR OF SAFETY= 1.79

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA2REV.120B)
LOCATION: SCOTTSDALE, AZ
DATE: 4- 5-1998
TIME: 12:50

PIPE DATA	
NOMINAL DIAMETER (in)=	120
MIN. WALL THICKNESS (in)=	12.0
X-SECT. MIN AREA (in**2)=	4976
MOMENT OF INTERIA (in**4)=	144.0
AREA FOR STRESS CALC (in**2)=	12.0
DISTANCE FROM MID-SEC TO NA (in)=	.2

LIVE LOAD DATA	
DESCRIPTION=	HS20
POINT LOAD (LBS)=	16000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	.1
WIDTH OF UNIFORM LOAD (in)=	144.0

SOIL DATA	
TRENCH HEIGHT (ft)=	3.0
TOTAL COVER HEIGHT (ft)=	19.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	.6
MARSTON LOAD (psi)=	14.2

MISC DATA	
CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	15.0
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA2REV.120B)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	15351	-12747	1555	109	1946
45.0	-84	-425	142	0	243
90.0	-15520	13103	-1791	-109	-2181
135.0	-84	281	-161	0	-407
180.0	15351	-13748	1990	109	3259

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-729	11	0	96
45.0	-467	-382	-29	-2	70
90.0	-935	0	-107	-6	34
135.0	-467	-414	-77	-2	112
180.0	0	-866	-10	0	218

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-467	650	-45	4	-55
90.0	0	1438	-10	1	-17
135.0	468	1448	62	-4	76
180.0	0	0	0	-12	43

PIMA ROAD THREE BASINS (PIMA2REV.120B)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	4266	-718	0
45.0	-369	-883	140
90.0	-4319	-1049	1428
135.0	33	-963	1973
180.0	3701	-877	-12

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-242	12.34	112	4.38
45.0	-57	51.90	-88	33.84
90.0	98	5.03	-261	11.45
135.0	-81	36.68	-78	37.97
180.0	-231	12.93	76	6.46

MINIMUM FACTOR OF SAFETY= 4.38

STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-240	12.47	277	1.78
45.0	16	31.49	5	98.08
90.0	272	1.81	-268	11.14
135.0	23	21.39	-7	365.56
180.0	-275	10.88	304	1.62

MINIMUM FACTOR OF SAFETY= 1.62

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA2REV.108A)
LOCATION: SCOOTSDALE, AZ
DATE: 4- 5-1998
TIME: 13: 3

PIPE DATA	
NOMINAL DIAMETER (in)=	108
MIN. WALL THICKNESS (in)=	10.5
X-SECT. MIN AREA (in**2)=	3909
MOMENT OF INTERIA (in**4)=	96.5
AREA FOR STRESS CALC (in**2)=	10.5
DISTANCE FROM MID-SEC TO NA (in)=	.2

LIVE LOAD DATA	
DESCRIPTION=	HS20
POINT LOAD (LBS)=	16000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	.4
WIDTH OF UNIFORM LOAD (in)=	129.0

SOIL DATA	
TRENCH HEIGHT (ft)=	3.0
TOTAL COVER HEIGHT (ft)=	10.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	.5
MARSTON LOAD (psi)=	8.1

MISC DATA	
CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	7.5
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA2REV.108A)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	7039	-5191	1097	317	1405
45.0	-36	-241	101	-1	174
90.0	-7112	5436	-1262	-319	-1575
135.0	-36	184	-113	-1	-291
180.0	7039	-5794	1403	317	2340

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-322	9	0	78
45.0	-238	-173	-23	-10	57
90.0	-477	0	-84	-20	27
135.0	-238	-194	-60	-10	90
180.0	0	-414	-8	0	176

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-238	283	-35	14	-44
90.0	0	631	-8	5	-13
135.0	239	652	48	-15	61
180.0	0	0	0	-42	34

PIMA ROAD THREE BASINS (PIMA2REV.108A)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	3260	-313	0
45.0	-179	-446	22
90.0	-3259	-583	627
135.0	32	-505	923
180.0	2964	-423	-42

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-212	14.11	142	3.47
45.0	-31	92.35	-51	57.62
90.0	127	3.88	-227	13.17
135.0	-49	60.03	-46	64.49
180.0	-205	14.53	116	4.24

MINIMUM FACTOR OF SAFETY= 3.47

STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-243	12.29	264	1.87
45.0	3	159.05	2	200.42
90.0	258	1.91	-268	11.17
135.0	15	33.11	-12	223.97
180.0	-280	10.68	296	1.66

MINIMUM FACTOR OF SAFETY= 1.66

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA2REV.108B)
LOCATION: SCOTTSDALE, AZ
DATE: 4- 5-1998
TIME: 13:25

PIPE DATA	
NOMINAL DIAMETER (in)=	108
MIN. WALL THICKNESS (in)=	10.5
X-SECT. MIN AREA (in**2)=	3909
MOMENT OF INTERIA (in**4)=	96.5
AREA FOR STRESS CALC (in**2)=	10.5
DISTANCE FROM MID-SEC TO NA (in)=	.2

LIVE LOAD DATA	
DESCRIPTION=	MAINTENANCE
POINT LOAD (LBS)=	6000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	13.6
WIDTH OF UNIFORM LOAD (in)=	21.0

SOIL DATA	
TRENCH HEIGHT (ft)=	1.0
TOTAL COVER HEIGHT (ft)=	1.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	2.2
MARSTON LOAD (psi)=	.9

MISC DATA	
CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	.0
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA2REV.108B)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	778	-8895	1097	11878	1405
45.0	-3	-989	101	-62	174
90.0	-785	10114	-1262	-12002	-1575
135.0	-3	884	-113	-62	-291
180.0	778	-11545	1403	11878	2340

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-484	9	0	78
45.0	-25	-295	-23	-402	57
90.0	-52	0	-84	-805	27
135.0	-25	-390	-60	-402	90
180.0	0	-887	-8	0	176

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-25	390	-35	524	-44
90.0	0	903	-8	171	-13
135.0	26	1077	48	-615	61
180.0	0	0	0	-1611	34

PIMA ROAD THREE BASINS (PIMA2REV.108B)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	4857	-475	0
45.0	-956	-748	852
90.0	-3938	-943	1065
135.0	703	-880	536
180.0	2514	-896	-1611

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-316	9.45	211	2.33
45.0	-17	169.28	-121	24.62
90.0	131	3.77	-297	10.07
135.0	-122	24.32	-46	64.11
180.0	-225	13.26	47	10.41

MINIMUM FACTOR OF SAFETY= 2.33

STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-388	7.72	293	1.68
45.0	-21	135.95	-106	27.97
90.0	222	2.22	-378	7.93
135.0	-97	30.49	-53	55.97
180.0	-340	8.81	188	2.63

MINIMUM FACTOR OF SAFETY= 1.68

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA2REV108C)
LOCATION: SCOTTSDALE, AZ
DATE: 4- 6-1998
TIME: 15:26

PIPE DATA

NOMINAL DIAMETER (in)=	108
MIN. WALL THICKNESS (in)=	10.5
X-SECT. MIN AREA (in**2)=	3909
MOMENT OF INTERIA (in**4)=	96.5
AREA FOR STRESS CALC (in**2)=	10.5
DISTANCE FROM MID-SEC TO NA (in)=	.2

LIVE LOAD DATA

DESCRIPTION=	HS20
POINT LOAD (LBS)=	16000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	4.0
WIDTH OF UNIFORM LOAD (in)=	63.0

SOIL DATA

TRENCH HEIGHT (ft)=	3.0
TOTAL COVER HEIGHT (ft)=	3.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	.5
MARSTON LOAD (psi)=	2.6

MISC DATA

CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	.0
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA2REV108C)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	2283	-2725	1097	3519	1405
45.0	-11	-228	101	-18	174
90.0	-2306	2996	-1262	-3556	-1575
135.0	-11	197	-113	-18	-291
180.0	2283	-3328	1403	3519	2340

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-157	9	0	78
45.0	-76	-90	-23	-118	57
90.0	-154	0	-84	-238	27
135.0	-76	-111	-60	-118	90
180.0	0	-248	-8	0	176

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-76	132	-35	155	-44
90.0	0	300	-8	51	-13
135.0	77	335	48	-182	61
180.0	0	0	0	-477	34

PIMA ROAD THREE BASINS (PIMA2REV108C)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	4173	-148	0
45.0	-158	-310	173
90.0	-4130	-478	342
135.0	53	-370	279
180.0	3877	-257	-477

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-247	12.10	206	2.39
45.0	-20	144.52	-37	78.86
90.0	186	2.65	-263	11.37
135.0	-37	78.43	-31	92.31
180.0	-241	12.41	180	2.74

MINIMUM FACTOR OF SAFETY= 2.39

STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-318	9.40	288	1.71
45.0	-24	119.51	-22	127.93
90.0	277	1.78	-343	8.71
135.0	-12	225.30	-38	76.33
180.0	-355	8.42	321	1.54

MINIMUM FACTOR OF SAFETY= 1.54

TERRAIN ENGINEERING INC.

6940 Tremont Rd

Dixon, CA 95620

CAST-IN-PLACE EARTH REINFORCED CONCRETE PIPE

STRUCTURAL ANALYSIS

CAPLCOP v. 1.04

TITLE: PIMA ROAD THREE BASINS (PIMA3ALT96)
LOCATION: SCOTTSDALE, AZ
DATE: 4- 5-1998
TIME: 14:26

PIPE DATA	
NOMINAL DIAMETER (in)=	96
MIN. WALL THICKNESS (in)=	9.0
X-SECT. MIN AREA (in**2)=	2969
MOMENT OF INTERIA (in**4)=	60.8
AREA FOR STRESS CALC (in**2)=	9.0
DISTANCE FROM MID-SEC TO NA (in)=	.1

LIVE LOAD DATA	
DESCRIPTION=	HS20
POINT LOAD (LBS)=	16000.0
SOIL DISTRIBUTION=	7.00 ACROSS
=	8.00 DOWN
UNIFORM LOAD ON THE PIPE (psi)=	1.5
WIDTH OF UNIFORM LOAD (in)=	105.0

SOIL DATA	
TRENCH HEIGHT (ft)=	3.0
TOTAL COVER HEIGHT (ft)=	5.0
UNIT WEIGHT OF FILL SOIL (pcf)=	120
UNIT WEIGHT OF IN-SITU SOIL (pcf)=	115
RANKINE COEFFICIENT OF IN-SITU SOIL=	.5
MARSTON LOAD (psi)=	4.2

MISC DATA	
CONCRETE STRENGTH (psi)=	3000
MODULUS RUPTURE (psi)=	493
WATER HEIGHT OVER PIPE CROWN (ft)=	.0
UNIT WEIGHT OF CONCRETE (pcf)=	150
UNIT WEIGHT OF WATER (pcf)=	62.4

PIMA ROAD THREE BASINS (PIMA3ALT96)

RESULTS OF ANALYSIS

MOMENTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	MOMENT MARSTON (in-lbs/in)	MOMENT LATERAL (in-lbs/in)	MOMENT DEAD (in-lbs/in)	MOMENT LIVE (in-lbs/in)	MOMENT WATER (in-lbs/in)
.0	2894	-2537	738	995	975
45.0	-13	-160	68	-4	120
90.0	-2922	2721	-849	-1004	-1094
135.0	-13	135	-75	-4	-199
180.0	2894	-2956	945	995	1613

RING THRUSTS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	THRUST MARSTON (lbs/in)	THRUST LATERAL (lbs/in)	THRUST DEAD (lbs/in)	THRUST LIVE (lbs/in)	THRUST WATER (lbs/in)
.0	0	-171	7	0	61
45.0	-110	-95	-17	-37	44
90.0	-221	0	-63	-75	21
135.0	-110	-112	-45	-37	71
180.0	0	-243	-6	0	138

SHEARS AT LOCATIONS IN PIPE CROSS SECTION

LOCATION (deg from crown)	SHEAR MARSTON (lbs/in)	SHEAR LATERAL (lbs/in)	SHEAR DEAD (lbs/in)	SHEAR LIVE (lbs/in)	SHEAR WATER (lbs/in)
.0	0	0	0	0	0
45.0	-110	148	-27	50	-34
90.0	0	333	-6	16	-10
135.0	111	357	37	-57	48
180.0	0	0	0	-151	26

PIMA ROAD THREE BASINS (PIMA3ALT96)

TOTALS (without water loading)

LOCATION (deg)	MOMENT (in/lbs/in)	THRUST (lbs/in)	SHEAR (lbs/in)
.0	2089	-165	0
45.0	-112	-262	59
90.0	-2055	-361	342
135.0	39	-307	446
180.0	1877	-250	-151

STRESSES (p.s.i.) - without head & water Load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-177	16.89	132	3.74
45.0	-20	145.69	-36	80.49
90.0	116	4.23	-187	15.94
135.0	-36	80.64	-30	95.52
180.0	-170	17.55	107	4.60

MINIMUM FACTOR OF SAFETY= 3.74

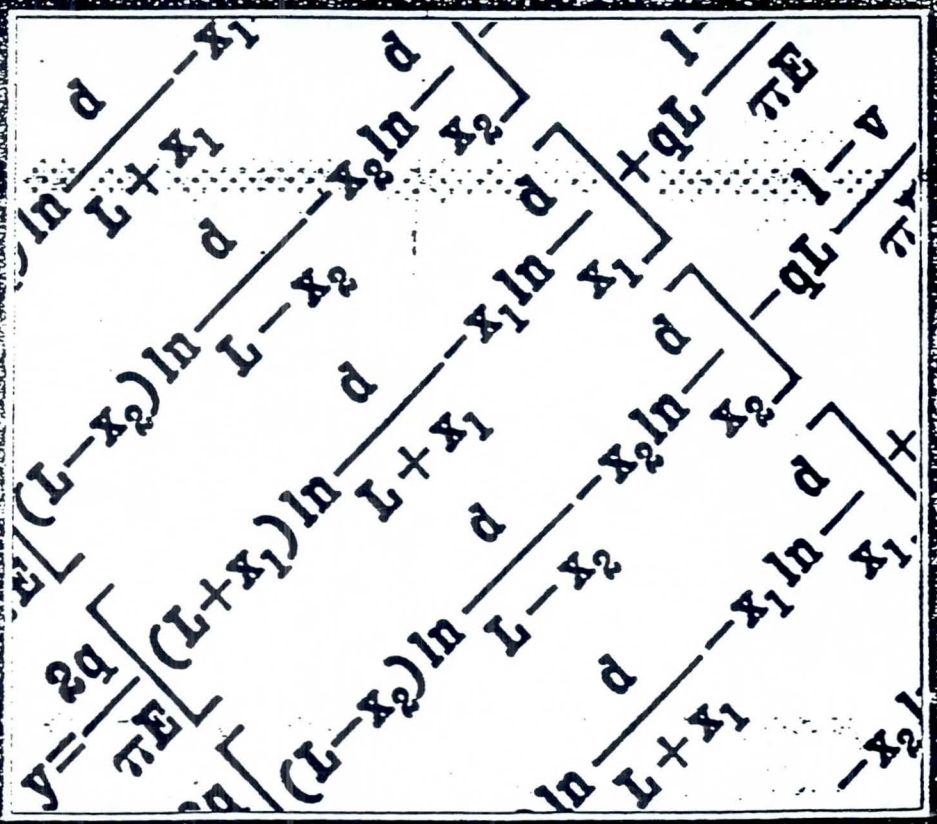
STRESSES (p.s.i.) - with head & water load
Tension (+); Compression (-)

LOCATION	OD FIBER	SAFETY FACTOR	ID FIBER	SAFETY FACTOR
.0	-244	12.24	209	2.36
45.0	-24	121.11	-23	126.51
90.0	202	2.44	-264	11.34
135.0	-13	212.79	-37	79.23
180.0	-277	10.77	239	2.07

MINIMUM FACTOR OF SAFETY= 2.07

Sixth Edition

Roark's Formulas for Stress & Strain



Warren C. Young

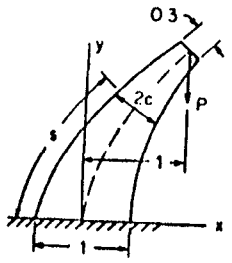


Figure 8.8

in Fig. 8.8. The vertical deflection at the loaded end is desired. To keep the use of specific dimensions to a minimum let the depth of the curved beam at the fixed end = 1.0, the thickness = 0.5, and the horizontal location of the load $P = 1.0$. The beam will be subdivided into eight segments, each spanning 0.25 units in the y direction. Normally a constant length along the span is used, but using constant Δy gives shorter spans where moments are larger and curvatures are sharper. The numerical calculations are also easier. Use will be made of the following expressions in order to provide the tabulated information from which the needed summation can be found. Note that y_i and x_i are used here as the y and x positions of the midlength of each segment.

$$x = 0.25y^2 \qquad \frac{dx}{dy} = 0.5y \qquad \frac{d^2x}{d^2y} = 0.5 \qquad \Delta l = \Delta y(1 + x_i)^{1/2}$$

$$R = \frac{[1 + (dx/dy)^2]^{3/2}}{d^2x/d^2y}$$

$$\frac{h}{c} = \frac{R}{c} - \frac{2}{\ln[(R/c + 1)/(R/c - 1)]} \quad \text{for } \frac{R}{2c} < 8 \quad \text{[see Eq. (1) and case 1 of Table 16]}$$

or

$$\frac{h}{c} = \frac{I_c}{RAc} = \frac{t(2c)^3}{12(Rt2c^2)} = \frac{c}{3R} \quad \text{for } \frac{R}{2c} > 8 \quad \text{[see Eq. (3)]}$$

The desired vertical deflection of the loaded end can be determined from Castigliano's theorem, using Eq. (9) for U_f in summation form rather than integral form. This reduces to

$$\delta = \frac{\delta U}{\delta P} = \frac{P}{E}\sum\left[\frac{(M/P)^2}{hR} + F\left(\frac{V}{P}\right)^2 2(1+\nu) + \left(\frac{N}{P}\right)^2 - 2\frac{M}{P}\frac{N}{P}\right]\frac{\Delta l}{A}$$

$$= \frac{P}{E}\sum\frac{\Delta l}{A}[B]$$

where $[B]$ and $[B]\Delta l/A$ are the last two columns in the table. The internal forces and moments can be determined from equilibrium equations as

$$\frac{M}{P} = -(1 - x_i) \qquad \theta_i = \tan^{-1}\frac{dx}{dy} \qquad V = P\sin\theta_i \qquad \text{and} \qquad N = -P\cos\theta_i$$

In the evaluation of the above equations for this problem, $F = 1.2$ and $\nu = 0.3$. In the table below one must fill in the first five columns in order to find the total length of the beam before the midsegment depth 2c can be found and the table completed.

Element no.	y_i	x_i	R	Δl	c	R/c
1	0.125	0.004	2.012	0.251	0.481	4.183
2	0.375	0.035	2.106	0.254	0.442	4.761
3	0.625	0.098	2.300	0.262	0.403	5.707
4	0.875	0.191	2.601	0.273	0.362	7.180
5	1.125	0.316	3.020	0.287	0.320	9.451
6	1.375	0.473	3.574	0.303	0.275	13.019
7	1.625	0.660	4.278	0.322	0.227	18.860
8	1.875	0.879	5.151	0.343	0.176	29.243
				2.295		

Element no.	h/c	M/P	V/P	N/P	$[B]$	$[B]\frac{\Delta l}{A}$
1	0.0809	−0.996	0.062	−0.998	11.695	6.092
2	0.0709	−0.965	0.184	−0.983	13.269	7.627
3	0.0589	−0.902	0.298	−0.954	14.370	9.431
4	0.0467	−0.809	0.401	−0.916	14.737	11.101
5	0.0354	−0.684	0.490	−0.872	14.007	12.569
6	0.0256	−0.527	0.567	−0.824	11.856	13.105
7	0.0177	−0.340	0.631	−0.776	8.049	11.431
8	0.0114	−0.121	0.684	−0.730	3.232	6.290
						77.555

Therefore, the deflection at the load and in the direction of the load is $77.56P/E$ in whatever units are chosen as long as the depth at the fixed end is unity. If one maintains the same length-to-depth ratio and the same shape, the deflection can be expressed as $\delta = 77.56P/(E2t_o)$, where t_o is the constant thickness of the beam.

Michael Plesha (Ref. 33) provided a finite-element solution for this configuration and obtained for the load point a vertically downward deflection of 72.4 units and a horizontal deflection of 88.3 units. The 22 elements he used were nine-node, quadratic displacement, Lagrange elements. The reader is invited to apply a horizontal dummy load and verify the horizontal deflection.

8.3 Circular Rings and Arches

In large pipelines, tanks, aircraft, and submarines the circular ring is an important structural element, and for correct design it is often necessary to calculate the stresses and deflections produced in such a ring under various conditions of loading and support. The circular arch of uniform section is often employed in buildings, bridges, and machinery.

Rings. A closed circular ring may be regarded as a *statically indeterminate beam* and analyzed as such by the use of Castigliano's second

theorem. In Table 17 are given formulas thus derived for the bending moments, tensions, shears, horizontal and vertical deflections, and rotations of the load point in the plane of the ring for various loads and supports. By superposition, these formulas can be combined so as to cover almost any condition of loading and support likely to occur.

The ring formulas are based on the following assumptions: (1) The ring is of uniform cross section and has symmetry about the plane of curvature. An exception to this requirement of symmetry can be made if moment restraints are provided to prevent rotation of each cross section out of its plane of curvature. Lacking the plane of symmetry and any external constraints, out-of-plane deformations will accompany in-plane loading. Meck, in Ref. 21, derives expressions concerning the coupling of in-plane and out-of-plane deformations of circular rings of arbitrary compact cross section and resulting instabilities. (2) All loadings are applied at the radial position of the centroid of the cross section. For thin rings this is of little concern, but for radially thick rings a concentrated load acting in other than a radial direction and not at the centroidal radius must be replaced by a statically equivalent load at the centroidal radius and a couple. For case 15, where the loading is due to gravity or a constant linear acceleration, and for case 21, where the loading is due to rotation around an axis normal to the plane of the ring, the proper distribution of loading through the cross section is accounted for in the formulas. (3) It is nowhere stressed beyond the elastic limit. (4) It is not so severely deformed as to lose its essentially circular shape. (5) Its deflection is due primarily to bending, but for thicker rings the deflections due to deformations caused by axial tension or compression in the ring and/or by transverse shear stresses in the ring may be included. To include these effects, we can evaluate first the coefficients α and β, the *axial stress deformation factor*, and the *transverse shear deformation factor*, and then the constants k_1 and k_2. Such corrections are more often necessary when composite or sandwich construction is employed. If no axial or shear stress corrections are desired, α and β are set equal to zero and the values of k are set equal to unity. (6) In the case of pipes acting as beams between widely spaced supports, the distribution of shear stress across the section of the pipe is in accordance with Art. 7.1, Eq. (2), and the direction of the resultant shear stress at any point of the cross section is tangential.

Note carefully the deformations given regarding the point or points of loading as compared with the deformations of the horizontal and vertical diameters. For many of the cases listed, the numerical values of load and deflection coefficients have been given for several positions of the loading. These coefficients do not include the effect of axial and shear deformation.

No account has been taken in Table 17 of the effect of radial stresses in the vicinity of the concentrated loads. These stresses and the local deformations they create can have a significant effect on overall ring deformations and peak stresses. In case 1 a reference is made to Art. 13.3 in which thick-walled rollers or rings are loaded on the outer ends of a diameter. The stresses and deflections given here are different from those predicted by the equations in case 1. If a concentrated load is used only for purposes of superposition, as is often the case, there is no cause for concern, but if an actual applied load is concentrated over a small region and the ring is sharply curved with thick walls, then one must be aware of the possible errors.

EXAMPLES

1. A pipe with a diameter of 13 ft and thickness of $\frac{1}{2}$ in is supported at intervals of 44 ft by rings, each ring being supported at the extremities of its horizontal diameter by vertical reactions acting at the centroids of the ring sections. It is required to determine the bending moments in a ring at the bottom, sides, and top, and the maximum bending moment when the pipe is filled with water.

Solution. We use the formulas for cases 4 and 20. Taking the weight of the water as 62.4 lb/ft^3 and the weight of the shell as 20.4 lb/ft^2, the total weight W of 44 ft of pipe carried by one ring is found to be 401,100 lb. Therefore, for case 20, $W = 401{,}100$; and for case 4, $W = 200{,}550$ and $\theta = \pi/2$. Assume a thin ring, $\alpha = \beta = 0$.

At bottom:

$$M = M_C = 0.2387(401{,}100)(6.5)(12) - 0.50(200{,}550)(78)$$
$$= 7.468(10^6) - 7.822(10^6) = -354{,}000 \text{ in-lb}$$

At top:

$$M = M_A = 0.0796(401{,}100)(78) - 0.1366(200{,}550)(78) = 354{,}000 \text{ in-lb}$$
$$N = N_A = 0.2387(401{,}100) - 0.3183(200{,}550) = 31{,}900 \text{ lb}$$
$$V = V_A = 0$$

At sides:

$$M = M_A - N_A R(1-u) + V_A Rz + LT_M$$

where for $x = \pi/2$, $u = 0$ $z = 1$, and $LT_M = (WR/\pi)(1 - u - xz/2) = [401{,}100(78)/\pi](1 - \pi/4) = 2.137(10^6)$ for case 20, and $LT_M = 0$ for case 4 since $z - s = 0$. Therefore

$$M = 354{,}000 - 31{,}900(78)(1-0) + 0 + 2.137(10^6) = 2800 \text{ in-lb}$$

The value of 2800 is due to the small differences in large numbers used in the superposition. An exact solution would give zero for this value. It is apparent that at least four digits must be carried.

To determine the location of maximum bending moment let $0 < x < \pi/2$ and

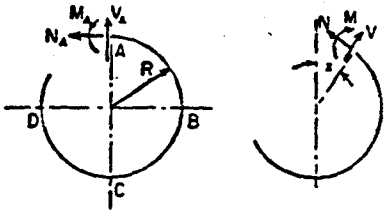
(text continues on p. 262)

TABLE 17 Formulas for circular rings

NOTATION: W = load (force); w and z = unit loads (force per unit of circumferential length); ρ = unit weight of contained liquid (force per unit volume); M_o = applied couple (force-length). M_A, M_B, M_C, and M are internal moments at A, B, C, and x, respectively, positive as shown. V_A, N, V_A, and V are internal forces, positive as shown. E = modulus of elasticity (force per unit area); ν = Poisson's ratio; A = cross-sectional area (length squared); R = radius to the centroid of the cross section (length); I = area moment of inertia of ring cross section about the principal axis perpendicular to the plane of the ring (length^4). [Note that for a pipe or cylinder, a representative segment of unit axial length may be used by replacing EI by $Et^3/12(1-\nu^2)$.] h = positive distance measured radially inward from the centroidal axis of the cross section to the neutral axis of pure bending (see Art. 8.1). θ, x, and ϕ are angles (radians) and are limited to the range zero to π for all cases except 18 and 19; $s = \sin\theta$, $c = \cos\theta$, $z = \sin x$, $u = \cos x$, $n = \sin\phi$, and $e = \cos\phi$.

D_V and D_H are changes in the vertical and horizontal diameters, respectively, and an increase is positive. ΔL is the change in the lower half of the vertical diameter or the vertical motion relative to point C of a line connecting points B and D on the ring. Similarly ΔL_H is the vertical motion relative to point C of a horizontal line connecting the load points on the ring. D_{WH} is the change in length of a horizontal line connecting the load points on the ring. ψ is the angular rotation (radians) of the load point in the plane of the ring and is positive in the direction of positive θ. For the distributed loadings the load points just referred to are the points where the distributed loading starts, i.e., the position located by the angle θ. The reference to points A, B, and C and to the diameters refer to positions on a circle of radius R passing through the centroids of the several sections; i.e., diameter = $2R$. It is important to consider this when dealing with thick rings. Similarly, all concentrated and distributed loadings are assumed to be applied at the radial position of the centroid with the exception of the cases where the ring is loaded by its own weight or by dynamic loading, cases 15 and 21. In these two cases the actual radial distribution of load is considered. If the loading is on the outer or inner surfaces of thick rings, an equivalent loading at the centroidal radius R must be used. See the examples to determine how this might be accomplished.

The hoop-stress deformation factor is $\alpha = I/AR^2$ for thin rings or $\alpha = h/R$ for thick rings. The transverse (radial) shear deformation factor is $\beta = FEI/GAR^2$ for thin rings or $\beta = 2F(1+\nu)h/R$ for thick rings, where G is the shear modulus of elasticity and F is a shape factor for the cross section (see Art. 7.10). The following constants are defined to simplify the expressions which follow. Note that these constants are unity if no correction for hoop stress or shear stress is necessary or desired for use with thin rings. $k_1 = 1-\alpha+\beta$, $k_2 = 1-\alpha$.



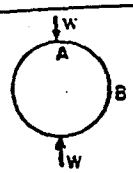
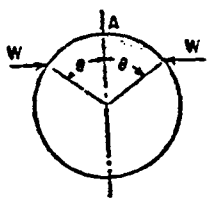
General formulas for moment, hoop load, and radial shear

$$M = M_A - N_A R(1-u) + V_A R z + LT_M$$
$$N = N_A u + V_A z + LT_N$$
$$V = -N_A z + V_A u + LT_V$$

where LT_M, LT_N, and LT_V are load terms given below for several types of load

Note: Due to symmetry in most of the cases presented, the loads beyond 180° are not included in the load terms. Only for cases 16, 17, and 19 should the equations for M, N, and V be used beyond 180°.

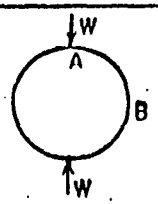
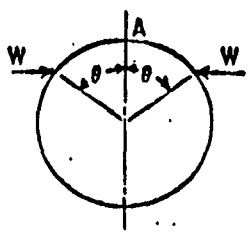
Note: The use of the bracket $\langle x-\theta\rangle^n$ is explained on page 98 and has a value of zero unless $x > \theta$

Reference no., loading, and load terms	Formulas for moments, loads, and deformations and some selected numerical values
1.  $LT_M = \frac{-WRz}{2}$ $LT_N = \frac{-Wz}{2}$ $LT_V = \frac{-Wu}{2}$	$M_A = \frac{WRk_2}{\pi}$ $N_A = 0$ $V_A = 0$ $D_H = \frac{WR^3}{EI}\left(\frac{k_1}{2} - k_2 + \frac{2k_2^2}{\pi}\right)$ $D_V = \frac{-WR^3}{EI}\left(\frac{\pi k_1}{4} - \frac{2k_2^2}{\pi}\right)$ Max $+M = M_A = 0.3183WRk_2$ Max $-M = M_B = -(0.5 - 0.3183k_2)WR$ If $\alpha = \beta = 0$, $D_H = 0.1366\frac{WR^3}{EI}$ and $D_V = -0.1488\frac{WR^3}{EI}$ *Note:* For concentrated loads on thick-walled rings, study the material in Art. 13.3 on hollow pins and rollers. Radial stresses under the concentrated loads have a significant effect not considered here.
2.  $LT_M = -WR(c-u)\langle x-\theta\rangle^n$ $LT_N = Wu\langle x-\theta\rangle^n$ $LT_V = -Wz\langle x-\theta\rangle^n$	$M_A = \frac{-WR}{\pi}[\pi - \theta(1-c) - s(k_2 - c)]$ $M_C = \frac{-WR}{\pi}[\theta(1+c) - s(k_2 + c)]$ $N_A = \frac{-W}{\pi}[\pi - \theta + u]$ $V_A = 0$ $D_H = \begin{cases} \frac{-WR^3}{EI\pi}[0.5\pi k_1\theta - \pi c) + 2k_2\theta c - 2k_2^2 s] & \text{if } \theta \le \frac{\pi}{2} \\ \frac{-WR^3}{EI\pi}[0.5\pi k_1(\pi - \theta + u) - 2k_2(\pi - \theta)c - 2k_2^2 s] & \text{if } \theta \ge \frac{\pi}{2} \end{cases}$ $D_V = \frac{WR^3}{EI}\left[\frac{k_1 s^2}{2} - k_2\left(1 - c + \frac{2\theta c}{\pi}\right) + \frac{2k_2^2 s}{\pi}\right]$ $\Delta L = \begin{cases} \frac{WR^3}{EI}\left[\frac{\theta c}{2} + \frac{k_1\theta - \pi c}{2\pi} - k_2\left(\frac{\theta c}{\pi} + \frac{s}{2}\right) + \frac{k_2^2 s}{\pi}\right] & \text{if } \theta \le \pi/2 \\ \frac{WR^3}{EI}\left[\frac{\pi - \theta c}{2} + \frac{k_1\theta - \pi c - \pi c^2}{2\pi} - k_2\left(1 + \frac{\theta c}{\pi} - \frac{s}{2}\right) + k_2^2 s/\pi\right] & \text{if } \theta \ge \pi/2 \end{cases}$ $\Delta L_H = \frac{WR^3}{EI\pi}[\pi - \theta\theta c + 0.5k_1 s^2\theta - \pi c + k_2(2\theta c^2 - \pi c^2 - \theta c - \theta) + k_2^2 s(1+c)]$ $D_{WH} = \frac{-WR^3}{EI\pi}[\pi - \theta(2\theta c^2 - k_1\pi c + \pi c^2 - 2\theta c - \pi\theta + \theta^2 - 2k_2\pi c(\pi - 2\theta) - 2k_2^2\pi^2]$ $\Delta\psi = \frac{-WR^2}{EI\pi}[\pi - \theta\theta c - k_2\pi c + \pi - 2\theta]$ Max $+M = \frac{WRs(k_2 - c^2)}{\pi}$ at $x = \theta$ Max $-M = \begin{cases} M_A & \text{if } \theta \le \frac{\pi}{2} \\ M_C & \text{if } \theta \ge \frac{\pi}{2} \end{cases}$ If $\alpha = \beta = 0$, $M = K_M WR$, $N = K_N W$, $D = K_D WR^3/EI$, $\Delta\psi = K_{\Delta\psi} WR^2/EI$, etc.

θ	30	45°	60°
K_{M_A}	−0.0903	−0.1538	−0.1955
K_{M_C}	0.0398	0.1125	0.2068
K_{N_A}	−0.9712	−0.9092	−0.8045
K_{N_B}	−0.0157	−0.0461	−0.0891
K_{D_H}	0.0207	0.0537	0.0930
K_{D_V}	0.0060	0.0179	0.0355
$K_{\Delta L}$	0.0119	0.0247	0.0391
$K_{\Delta L_H}$	−0.0060	−0.0302	−0.0770
$K_{D_{WH}}$	0.0244	0.0496	0.0590
$K_{\Delta\psi}$			

Note: [redacted] sym[redacted] in m[redacted] the [redacted] and 19 should the equations for M, N, an[redacted]e used beyond 180°. [redacted] 17.

Note: The use of the bracket $\langle x-\theta\rangle^0$ is explained on page 98 and has a value of zero unless $x > \theta$

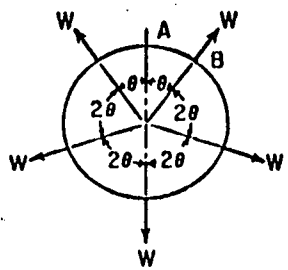
Reference no., loading, and load terms	Formulas for moments, loads, and deformations and some selected numerical values
1.  $LT_M = \dfrac{-WRz}{2}$ $\quad LT_N = \dfrac{-Wz}{2}$ $LT_v = \dfrac{-Wu}{2}$	$M_A = \dfrac{WRk_2}{\pi}$ $N_A = 0$ $V_A = 0$ $D_H = \dfrac{WR^3}{EI}\left(\dfrac{k_1}{2} - k_2 + \dfrac{2k_2^2}{\pi}\right)$ $D_V = \dfrac{-WR^3}{EI}\left(\dfrac{\pi k_1}{4} - \dfrac{2k_2^2}{\pi}\right)$ Max $+M = M_A = 0.3183WRk_2$ Max $-M = M_B = -(0.5 - 0.3183k_2)WR$ If $\alpha = \beta = 0$, $D_H = 0.1366\dfrac{WR^3}{EI}$ and $D_V = -0.1488\dfrac{WR^3}{EI}$ *Note:* For concentrated loads on thick-walled rings, study the material in Art. 13.3 on hollow pins and rollers. Radial stresses under the concentrated loads have a significant effect not considered here.
2.  $LT_M = -WR(c-u)\langle x-\theta\rangle^0$ $LT_N = Wu\langle x-\theta\rangle^0$ $LT_V = -Wz\langle x-\theta\rangle^0$	$M_A = \dfrac{-WR}{\pi}[(\pi-\theta)(1-c) - s(k_2-c)]$ $M_C = \dfrac{-WR}{\pi}[\theta(1+c) - s(k_2+c)]$ $N_A = \dfrac{-W}{\pi}[\pi - \theta + sc]$ $V_A = 0$ $D_H = \begin{cases} \dfrac{-WR^3}{EI\pi}[0.5\pi k_1(\theta - sc) + 2k_2\theta c - 2k_2^2 s] & \text{if } \theta \le \dfrac{\pi}{2} \\ \dfrac{-WR^3}{EI\pi}[0.5\pi k_1(\pi - \theta + sc) - 2k_2(\pi-\theta)c - 2k_2^2 s] & \text{if } \theta \ge \dfrac{\pi}{2} \end{cases}$ $D_V = \dfrac{WR^3}{EI}\left[\dfrac{k_1 s^2}{2} - k_2\left(1 - c + \dfrac{2\theta c}{\pi}\right) + \dfrac{2k_2^2 s}{\pi}\right]$ $\Delta L = \begin{cases} \dfrac{WR^3}{EI}\left[\dfrac{\theta c}{2} + \dfrac{k_1(\theta - sc)}{2\pi} - k_2\left(\dfrac{\theta c}{\pi} + \dfrac{s}{2}\right) + \dfrac{k_2^2 s}{\pi}\right] & \text{if } \theta \le \pi/2 \\ \dfrac{WR^3}{EI}\left[\dfrac{(\pi-\theta)c}{2} + \dfrac{k_1(\theta - sc - \pi c^2)}{2\pi} - k_2\left(1 + \dfrac{\theta c}{\pi} - \dfrac{s}{2}\right) + k_2^2 s/\pi\right] & \text{if } \theta \ge \pi/2 \end{cases}$ $\Delta L_W = \dfrac{WR^3}{EI\pi}[(\pi-\theta)\theta c + 0.5k_1 s^2(\theta - sc) + k_2(2\theta s^2 - \pi s^2 - \theta c - \theta) + k_2^2 s(1+c)]$ $D_{WH} = \dfrac{-WR^3}{EI\pi}[(\pi-\theta)2\theta c^2 - k_1(\pi sc + s^2c^2 - 2\theta sc - \pi\theta + \theta^2) - 2k_2 sc(\pi - 2\theta) - 2k_2^2 s^2]$ $\Delta\psi = \dfrac{-WR^2}{EI\pi}[(\pi-\theta)\theta c - k_2 s(sc + \pi - 2\theta)]$ Max $+M = \dfrac{WRs(k_2 - c^2)}{\pi}$ at $x = \theta$ Max $-M = \begin{cases} M_A & \text{if } \theta \le \dfrac{\pi}{2} \\ M_C & \text{if } \theta \ge \dfrac{\pi}{2} \end{cases}$ If $\alpha = \beta = 0$, $M = K_M WR$, $N = K_N W$, $D = K_D WR^3/EI$, $\Delta\psi = K_{\Delta\psi} WR^2/EI$, etc.

θ	30°	45°	60°
K_{M_A}	−0.0903	−0.1538	−0.1955
K_{M_C}	0.0398	0.1125	0.2068
K_{N_A}	−0.9712	−0.9092	−0.8045
K_{D_H}	−0.0157	−0.0461	−0.0891
K_{D_V}	0.0207	0.0537	0.0930
$K_{\Delta L}$	0.0060	0.0179	0.0355
$K_{\Delta L_W}$	0.0119	0.0247	0.0391
$K_{D_{WH}}$	−0.0060	−0.0302	−0.0770
$K_{\Delta\psi}$	0.0244	0.0496	0.0590

TABLE 17 Formulas for circular rings (*Continued*)

Reference no., loading, and load terms	Formulas for moments, loads, and deformations and some selected numerical values

7. Ring under any number of equal radial forces equally spaced



For $0 < x < \theta$ $\quad M = \dfrac{WR(u/s - k_2/\theta)}{2} \quad N = \dfrac{Wu}{2s} \quad V = \dfrac{-Wz}{2s}$

Max $+M = M_A = \dfrac{WR(1/s - k_2/\theta)}{2}$ $\quad$ Max $-M = \dfrac{-WR}{2}\left(\dfrac{k_2}{\theta} - \dfrac{c}{s}\right)$ at each load position

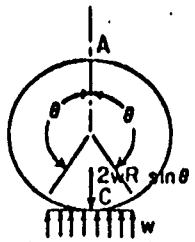
Radial displacement at each load point $= \Delta R_H = \dfrac{WR^3}{EI}\left[\dfrac{k_1(\theta - sc)}{4s^2} + \dfrac{k_2 c}{2s} - \dfrac{k_2^2}{2\theta}\right]$

Radial displacement at $x = 0, 2\theta, \ldots = \Delta R_A = \dfrac{-WR^3}{EI}\left[\dfrac{k_1(s - \theta c)}{4s^2} - \dfrac{k_2}{2s} + \dfrac{k_2^2}{2\theta}\right]$

If $\alpha = \beta = 0$, $M = K_M WR$, $\Delta R = K_{\Delta R} WR^3/EI$

θ	15°	30°	45°	60°	90°
K_{M_A}	0.02199	0.04507	0.07049	0.09989	0.18169
K_{M_H}	−0.04383	−0.08890	−0.13662	−0.18879	−0.31831
$K_{\Delta R_H}$	0.00020	0.00168	0.00608	0.01594	0.07439
$K_{\Delta R_A}$	−0.00018	−0.00148	−0.00539	−0.01426	−0.06831

8.



$\left(\text{Note: } \theta \geq \dfrac{\pi}{2}\right)$

$I.T_M = \dfrac{-wR^2}{2}(z - s)^2\langle x - \theta\rangle^0$

$I.T_N = -wRz(z - s)\langle x - \theta\rangle^0$

$I.T_V = -wRu(z - s)\langle x - \theta\rangle^0$

$$M_A = \frac{wR^2}{2\pi}\left[\pi(s^2 - 0.5) - \frac{sc - \theta}{2} - s^2\left(\theta + \frac{2s}{3}\right) - k_2(2s + sc - \pi + \theta)\right]$$

$$M_C = \frac{-wR^2}{2\pi}\left[\frac{\pi}{2} + \frac{sc}{2} - \frac{\theta}{2} + \theta s^2 - \frac{2s^3}{3} + k_2(2s + sc - \pi + \theta)\right]$$

$$N_A = \frac{-wRs^3}{3\pi}$$

$$V_A = 0$$

$$D_H = \frac{-wR^4}{2EI\pi}\left[\frac{k_1\pi s^3}{3} + k_2(\pi - 2\pi s^2 - \theta + 2\theta s^2 + sc) + 2k_2^2(2s + sc - \pi + \theta)\right]$$

$$D_V = \frac{wR^4}{2EI\pi}\left[k_1\pi\left(\pi s - \theta s - \tfrac{2}{3} - c + \frac{c^3}{3}\right) - k_2(\pi c^2 + sc - \theta + 2\theta s^2) - 2k_2^2(2s + sc - \pi + \theta)\right]$$

$$\Delta L = \frac{wR^4}{4EI\pi}\left[\pi(\pi - \theta)\frac{2s^2 - 1}{2} - \frac{\pi sc}{2} - 2\pi k_1\left(\tfrac{2}{3} - \pi s + c + \theta s - \frac{c^3}{3} + \frac{s^3}{3\pi}\right) - k_2(sc + \pi - \theta + 2\theta s^2 + 2s\pi - \pi^2 + \pi\theta + \pi sc) - 2k_2^2(2s + sc - \pi + \theta)\right]$$

Max $+M$ occurs at an angular position x_1 where $x_1 > \theta$, $x_1 > 123.1°$, and

$$\tan x_1 + \frac{3\pi(s - \sin x_1)}{s^3} = 0$$

Max $-M = M_C$

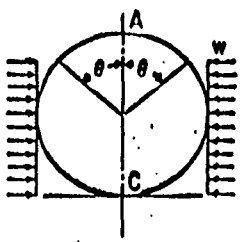
If $\alpha = \beta = 0$, $M = K_M wR^2$, $N = K_N wR$, $D = K_D wR^4/EI$, etc.

θ	90°	120°	135°	150°
K_{M_A}	−0.0494	−0.0329	−0.0182	−0.0065
K_{N_A}	−0.1061	−0.0689	−0.0375	−0.0133
K_{M_C}	−0.3372	−0.2700	−0.1932	−0.1050
K_{D_H}	−0.0533	−0.0362	−0.0204	−0.0074
K_{D_V}	0.0655	0.0464	0.0276	0.0108
$K_{\Delta L}$	0.0448	0.0325	0.0198	0.0080

TABLE 17 Formulas for circular rings (*Continued*)

Reference no., loading, and load terms	Formulas for moments, loads, and deformations and some selected numerical values

10.



$$I.T_M = \frac{-wR^2}{2}(c-u)^2\langle x-\theta\rangle^0$$

$$I.T_N = wRu(c-u)\langle x-\theta\rangle^0$$

$$I.T_V = wRz(c-u)\langle x-\theta\rangle^0$$

$$M_A = \frac{-wR^2}{4\pi}\left[(\pi-\theta)(4c+2s^2-1)+s\left(4-\frac{4s^2}{3}-c\right)-2k_2(\pi-\theta+sc)\right]$$

$$M_C = \frac{-wR^2}{4\pi}\left[3\pi+\theta+4\theta c-2\theta s^2-4s-sc+\frac{4s^3}{3}-2k_2(\pi-\theta+sc)\right]$$

$$N_A = \frac{-wR}{\pi}\left(\pi c+s-\theta c-\frac{s^3}{3}\right)$$

$$V_A = 0$$

$$D_H = \begin{cases} \dfrac{-wR^4}{6EI\pi}\left[\pi k_1(s^3+3\theta c+4-3s)+3k_2(\pi-\theta+2\theta c^2-sc)-6k_2^2(\pi-\theta+sc)\right] & \text{for } \theta \le \dfrac{\pi}{2} \\ \dfrac{-wR^4}{2EI\pi}\left\{\pi k_1\left[c(\pi-\theta)+s-\dfrac{s^3}{3}\right]+k_2[(\pi-\theta)(2s^2-1)-sc]-2k_2^2(\pi-\theta+sc)\right\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

$$D_V = \frac{wR^4}{6EI\pi}\left\{\pi k_1(2-c^3+3c)+3k_2[2\theta s^2-\theta+sc-\pi(1+2c+s^2)]+6k_2^2(\pi-\theta+sc)\right\}$$

$$\Delta L = \begin{cases} \dfrac{wR^4}{12EI\pi}\left[1.5\pi(\theta-2\theta s^2-sc)+2k_1(2\pi+s^3+3\theta c-3s)+3k_2(sc+\theta\pi+2\theta s^2-3\pi-\theta-\pi sc)+6k_2^2(\pi-\theta+sc)\right] & \text{for } \theta \le \dfrac{\pi}{2} \\ \dfrac{wR^4}{12EI\pi}\left\{1.5\pi[(\pi-\theta)(1-2s^2)+sc]+2k_1(2\pi+s^3+3\theta c-3s-\pi c^3)\right. & \\ \qquad\qquad \left.+3k_2[(\pi+1)(\pi-\theta+sc)+2\theta s^2-4\pi(1+c)]+6k_2^2(\pi-\theta+sc)\right\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

Max $+M$ occurs at an angular position x_1 where $x_1 > \theta$, $x_1 > 90°$, and

$$x_1 = \arccos\frac{s^3/3+\theta c-s}{\pi}$$

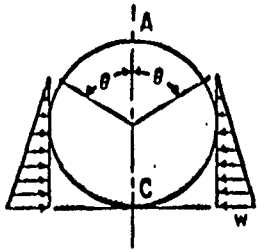
Max $-M = M_C$

If $\alpha = \beta = 0$, $M = K_M wR^2$, $N = K_N wR$, $D = K_D wR^4/EI$, etc.

θ	0°	30°	45°	60°	90°	120°	135°	150°
K_{M_A}	−0.2500	−0.2434	−0.2235	−0.1867	−0.0872	−0.0185	−0.0052	−0.00076
K_{N_A}	−1.0000	−0.8676	−0.7179	−0.5401	−0.2122	−0.0401	−0.0108	−0.00155
K_{M_C}	−0.2500	−0.2492	−0.2448	−0.2315	−0.1628	−0.0633	−0.0265	−0.00663
K_{D_H}	−0.1667	−0.1658	−0.1610	−0.1470	−0.0833	−0.0197	−0.0057	−0.00086
K_{D_V}	0.1667	0.1655	0.1596	0.1443	0.0833	0.0224	0.0071	0.00118
$K_{\Delta L}$	0.0833	0.0830	0.0812	0.0756	0.0486	0.0147	0.0049	0.00086

K_{D_V}	0.1667	0.1655	1596	0.1443	0.0833	0.0224	0.0071	0.00118
K_{AL}	0.0833	0.0830	812	0.0756	0.0486	0.0147	0.0049	0.00086

11.



$$LT_M = \frac{-wR^2}{6(1+c)}(c-u)^3\langle x-\theta\rangle^0$$

$$LT_N = \frac{wRu}{2(1+c)}(c-u)^2\langle x-\theta\rangle^0$$

$$LT_V = \frac{wRz}{2(1+c)}(c-u)^2\langle x-\theta\rangle^0$$

$$M_A = \frac{-wR^2}{(1+c)\pi}\left[(\pi-\theta)\frac{3+12c^2+2c+4cs^2}{24} - \frac{3s^3c-3s-5s^3}{36} + \frac{5sc}{8} - k_2\left(\frac{\pi c}{2} - \frac{\theta c}{2} + \frac{s^3}{3} + \frac{sc^2}{2}\right)\right]$$

$$M_C = \frac{-wR^2}{(1+c)\pi}\left[(\pi-\theta)\frac{-3-12c^2+2c+4cs^2}{24} + \frac{\pi(1+c)^3}{6} + \frac{3s^3c+3s+5s^3}{36} - \frac{5sc}{8} - k_2\left(\frac{\pi c}{2} - \frac{\theta c}{2} + \frac{s^3}{3} + \frac{sc^2}{2}\right)\right]$$

$$N_A = \frac{-wR}{(1+c)\pi}\left[(\pi-\theta)\frac{1+4c^2}{8} + \frac{5sc}{8} - \frac{s^3c}{12}\right]$$

$$V_A = 0$$

$$D_H = \begin{cases} \dfrac{-wR^4}{EI(1+c)\pi}\left\{\pi k_1\left(\dfrac{\theta+40c^2-5sc}{16} + \dfrac{s^3c+16c}{24}\right) - k_2\left(\dfrac{5sc^2+30c+60s^2c-8s}{18} - \dfrac{\pi c}{2}\right) - k_2^2\left[c(\pi-\theta) + \dfrac{2s^3}{3} + sc^2\right]\right\} & \text{for } \theta \le \dfrac{\pi}{2} \\[2ex] \dfrac{-wR^4}{EI(1+c)\pi}\left\{\pi k_1\left[(\pi-\theta)\dfrac{1+4c^2}{16} + \dfrac{5sc}{16} - \dfrac{s^3c}{24}\right] - k_2\left[\dfrac{5sc^2-8s}{18} - (\pi-\theta)\dfrac{c+2s^2c}{6}\right] - k_2^2\left[c(\pi-\theta) + s - \dfrac{s^3}{3}\right]\right\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

$$D_V = \frac{wR^4}{EI(1+c)}\left\{k_1\left[\frac{(1+c)^2}{6} - \frac{s^4}{24}\right] + k_2\left(\frac{5sc^2+30c+60s^2c-8s}{18\pi} + \frac{s^2}{2} + \frac{c^3}{6} - c - \frac{2}{3}\right) + k_2^2\frac{c(\pi-\theta)+s-s^3/3}{\pi}\right\}$$

$$\Delta L = \begin{cases} \dfrac{wR^4}{EI(1+c)}\left\{\dfrac{3s+5s^3+60c^3-90c-16}{72} + k_1\left(\dfrac{c}{3} + \dfrac{1}{16} + \dfrac{120c^2+30+2s^3c-15sc}{48\pi}\right) \right. \\ \qquad \left. + k_2\left[\dfrac{1-s^3}{6} - \dfrac{c(3+sc-\theta)}{4} + \dfrac{30c+60s^2c-3s-5s^3}{36\pi}\right] + k_2^2\dfrac{c(\pi-\theta)/2+sc^2/2+s^3/3}{\pi}\right\} & \text{for } \theta \le \dfrac{\pi}{2} \\[2ex] \dfrac{wR^4}{EI(1+c)}\left\{\dfrac{-(\pi-\theta)c(1+2s^2)}{24} - \dfrac{sc^2}{24} - \dfrac{s^3}{9} + k_1\left(\dfrac{c}{3} + \dfrac{1}{16} - \dfrac{c^4}{24} + \dfrac{120c^2+30+2s^3c-15sc}{48\pi}\right) \right. \\ \qquad \left. + k_2\left[\dfrac{2s-2+sc^2}{12} + \dfrac{c(\pi-\theta-3-2c)}{4} + \dfrac{30c+60s^2c-3s-5s^3}{36\pi}\right] + k_2^2\dfrac{3c(\pi-\theta)+2s+sc^2}{6\pi}\right\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

Max $+M$ occurs at an angular position x_1 where $x_1 > \theta$, $x_1 > 96.8°$, and

$$x_1 = \arccos\left\{c - \left[(c^2+0.25)\left(1-\frac{\theta}{\pi}\right) + \frac{sc(5-2s^2/3)}{4\pi}\right]^{1/2}\right\}$$

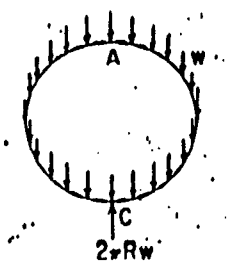
Max $-M = M_C$

If $\alpha = \beta = 0$, $M = K_M wR^2$, $N = K_N wR$, $D = K_D wR^4/EI$, etc.

θ	0°	30°	45°	60°	90°	120°	135°	150°
K_{M_A}	−0.1042	−0.0939	−0.0808	−0.0635	−0.0271	−0.0055	−0.0015	−0.00022
K_{N_A}	−0.3125	−0.2679	−0.2191	−0.1628	−0.0625	−0.0116	−0.0031	−0.00045
K_{M_C}	−0.1458	−0.1384	−0.1282	−0.1129	−0.0608	−0.0239	−0.0096	−0.00232
K_{D_H}	−0.0833	−0.0774	−0.0693	−0.0575	−0.0274	−0.0059	−0.0017	−0.00025
K_{D_V}	0.0833	0.0774	0.0694	0.0579	0.0291	0.0071	0.0022	0.00035
$K_{\Delta L}$	0.0451	0.0424	0.0387	0.0332	0.0180	0.0048	0.0015	0.00026

$$\Delta L = \begin{cases} \dfrac{wR^4}{EI(\pi-\theta)^2}\left\{k_1\left(\dfrac{3s+2\theta-\theta c}{\pi}+\pi-2\theta-\dfrac{\pi s}{2}\right) + k_2\left[2+s-\theta+\dfrac{\pi^3}{8}+\dfrac{\theta^3}{6}-\dfrac{\theta\pi^2}{4}-(\pi-\theta)^2\right] + k_2^2\dfrac{(\pi-\theta)^3-6(\pi-\theta-s)}{3\pi}\right\} & \text{for } \theta \le \dfrac{\pi}{2} \\ \dfrac{wR^4}{EI(\pi-\theta)^2}\left\{k_1\left[\dfrac{3s+2\theta-\theta c}{\pi}-s(\pi-\theta)+3c\right] + k_2\left[\dfrac{(\pi-\theta)^3}{6}-(\pi-\theta)^2-\pi+\theta+s+2+2c\right] + k_2^2\dfrac{(\pi-\theta)^3-6(\pi-\theta-s)}{3\pi}\right\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

15. Ring supported at base and loaded by own weight per unit length of circumference w



$LT_M = -wR^2[xz + K_T(u-1)]$
$LT_N = -wRxz$
$LT_V = -wRxu$

$$M_A = wR^2\left[k_2 - 0.5 - \frac{(K_T-1)\beta}{k_1}\right] \qquad \text{where } K_T = 1 + \frac{I}{AR^2}$$

$$M_C = wR^2\left[k_2 + 0.5 + \frac{(K_T-1)\beta}{k_1}\right]$$

$$N_A = wR\left[0.5 + \frac{(K_T-1)k_2}{k_1}\right]$$

$$V_A = 0$$

$$D_H = \frac{wR^3}{EAh}\left(\frac{k_1\pi}{2} - k_2\pi + 2k_2^2\right)$$

$$D_V = \frac{-wR^3}{EAh}\left(\frac{k_1\pi^2}{4} - 2k_2^2\right)$$

$$\Delta L = \frac{-wR^3}{EAh}\left[1 + \frac{3k_1\pi^2}{16} - \frac{k_2\pi}{2} - k_2^2 + (K_T-1)\alpha\right]$$

Note: The constant K_T accounts for the radial distribution of mass in the ring.

Max $+M = M_C$
Max $-M$ occurs at an angular position x_1 where

$$\frac{x_1}{\tan x_1} = -0.5 + \frac{(K_T-1)\beta}{k_1}$$

For a thin ring where $K_T \approx 1$,

$$\text{Max } -M = -wR^2(1.6408 - k_2) \qquad \text{at } x = 105.23°$$

If $\alpha = \beta = 0$,

$$M_A = \frac{wR^2}{2}$$

$$N_A = \frac{wR}{2}$$

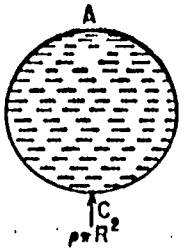
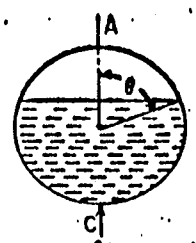
$$D_H = 0.4292\,\frac{wR^4}{EI}$$

$$D_V = -0.4674\,\frac{wR^4}{EI}$$

$$\Delta L = -0.2798\,\frac{wR^4}{EI}$$

$$\text{Max } +M = \tfrac{3}{2}wR^2 \text{ at } C$$

TABLE 17 Formulas for circular rings (*Continued*)

Reference no., loading, and load terms	Formulas for moments, loads, and deformations and some selected numerical values
16. Unit axial segment of pipe filled with liquid of weight per unit volume ρ and supported at the base  $LT_M = \rho R^3\left(1 - u - \frac{\pi\xi}{2}\right)$ $LT_N = \rho R^2\left(1 - u - \frac{\pi\xi}{2}\right)$ $LT_V = \rho R^2\left(\frac{\xi}{2} - \frac{\pi u}{2}\right)$	$M_A = \rho R^3\left(0.75 - \frac{k_2}{2}\right)$ $M_C = \rho R^3\left(1.25 - \frac{k_2}{2}\right)$ $N_A = 0.75\rho R^2$ $V_A = 0$ $D_H = \frac{\rho R^5 12(1-\nu^2)}{Et^3}\left[\frac{k_1\pi}{4} + k_2\left(2 - \frac{\pi}{2}\right) - k_2^2\right]$ $D_V = \frac{-\rho R^5 12(1-\nu^2)}{Et^3}\left(\frac{k_1\pi^2}{8} - 2k_2 + k_2^2\right)$ $\Delta L = \frac{-\rho R^5 12(1-\nu^2)}{Et^3}\left[\frac{k_1 3\pi^2}{32} - k_2\left(0.5 + \frac{\pi}{4}\right) + \frac{k_2^2}{2}\right]$ *Note:* For this case and case 17, $\alpha = \frac{t^2}{12R^2(1-\nu^2)}$ $\beta = \frac{t^2}{6R^2(1-\nu)}$ where t = pipe wall thickness Max $+M = M_C$ Max $-M = -\rho R^3\left(\frac{k_2}{2} - 0.1796\right)$ at $x = 105.23°$ If $\alpha = \beta = 0$, $D_H = 0.2146\,\frac{\rho R^5 12(1-\nu^2)}{Et^3}$ $D_V = -0.2337\,\frac{\rho R^5 12(1-\nu^2)}{Et^3}$ $\Delta L = -0.1399\,\frac{\rho R^5 12(1-\nu^2)}{Et^3}$
17. Unit axial segment of pipe partly filled with liquid of weight per unit volume ρ and supported at the base 	*Note:* see case 16 for expressions for α and β $M_A = \frac{\rho R^3}{4\pi}\{2\theta s^2 + 3sc - 3\theta + \pi + 2\pi c^2 + 2k_2[sc - 2s + (\pi - \theta)(1 - 2c)]\}$ $N_A = \frac{\rho R^2}{4\pi}[3sc + (\pi - \theta)(1 + 2c^2)]$ $V_A = 0$ $D_H = \begin{cases} \frac{\rho R^5 3(1-\nu^2)}{2Et^3\pi}\left\{k_1\pi(sc + 2\pi - 3\theta + 2\theta c^2) + 8k_2\pi\left(2c - sc - \frac{\pi}{2} + \theta\right) + 8k_2^2[(\pi - \theta)(1 - 2c) + sc - 2s]\right\} & \text{for } \theta \le \frac{\pi}{2} \\ \frac{\rho R^5 3(1-\nu^2)}{2Et^3\pi}\{k_1\pi[(\pi - \theta)(1 + 2c^2) + 3sc] + 8k_2^2[(\pi - \theta)(1 - 2c) + sc - 2s]\} & \text{for } \theta \ge \frac{\pi}{2} \end{cases}$ $D_V = \frac{-\rho R^5 3(1-\nu^2)}{2Et^3\pi}\{k_1\pi[s^2 + (\pi - \theta)(\pi - \theta + 2sc)] - 4k_2\pi(1 + c)^2 - 8k_2^2[(\pi - \theta)(1 - 2c) + sc - 2s]\}$	

$\rho R^2(\pi-\theta+sc)$

$$D_V = \frac{-\rho R^3 3(1-\nu^2)}{2Et^3\pi}\{k_1\pi[s^2+(\pi-\theta)(\pi-\theta+2sc), \quad 4k_2\pi(1+c)^2-8k_2^2[(\pi-\theta)(1-2c)+sc-2s]\}$$

$$LT_M = \frac{\rho R^2}{2}[2c-c(\pi-\theta+sc) - u(1+c^2)]\langle\pi-\theta\rangle^0$$

$$LT_N = \frac{\rho R^2}{2}[2c-c(\pi-\theta+sc) - u(1+c^2)]\langle\pi-\theta\rangle^0$$

$$LT_V = \frac{\rho R^2}{2}[2c^2-u(\pi-\theta+sc)]\langle\pi-\theta\rangle^0$$

$$\Delta L = \begin{cases} \dfrac{-\rho R^3 3(1-\nu^2)}{2Et^3\pi}\left\{k_1\left[20c^2+\theta-3sc+\pi^2\left(sc-\theta+\dfrac{3\pi}{4}\right)\right]+2k_2\pi[2+20c-2s-4c-\pi+\theta-sc] \right. \\ \qquad\qquad \left. -4k_2^2[(\pi-\theta)(1-2c)+sc-2s]\right\} & \text{for } \theta \le \dfrac{\pi}{2} \\ \dfrac{-\rho R^3 3(1-\nu^2)}{2Et^3\pi}\{k_1[20c^2+\theta-3sc+\pi(\pi-\theta)(\pi-\theta+2sc)-3\pi c^2] \\ \qquad\qquad +2k_2\pi[2s-2(1+c)^2-sc-(\pi-\theta)(1-2c)]-4k_2^2[(\pi-\theta)(1-2c)+sc-2s]\} & \text{for } \theta \ge \dfrac{\pi}{2} \end{cases}$$

$$\text{Max } +M = M_C = \frac{\rho R^3}{4\pi}\{4\pi c+\pi+20c^2+\theta-3sc+2k_2[(\pi-\theta)(1-2c)+sc-2s]\}$$

Max $-M$ occurs at an angular position x_1 where $x_1 > \theta$, $x_1 > 105.23°$, and x_1 is found from
$(\theta+20c^2-3sc-\pi)\tan x_1 + 2\pi(\theta-sc-x_1) = 0$

If $\alpha = \beta = 0$, $M = K_M\rho R^3$, $N = K_N\rho R^2$, $D = K_D\rho R^3 12(1-\nu^2)/Et^3$, etc.

θ	0°	30°	45°	60°	90°	120°	135°	150°
K_{MA}	0.2500	0.2290	0.1935	0.1466	0.0567	0.0104	0.0027	0.00039
K_{NA}	0.7500	0.6242	0.4944	0.3534	0.1250	0.0216	0.0056	0.00079
K_{MC}	0.7500	0.7216	0.6619	0.5649	0.3067	0.0921	0.0344	0.00778
$K_{D\theta}$	0.2146	0.2027	0.1787	0.1422	0.0597	0.0115	0.0031	0.00044
K_{DV}	−0.2337	−0.2209	−0.1955	−0.1573	−0.0700	−0.0150	−0.0043	−0.00066
K_{AL}	−0.1399	−0.1333	−0.1198	−0.0986	−0.0465	−0.0106	−0.0031	−0.00050

Summary of Hydraulic Review

The hydraulic impacts from the use of Cast-In-Place Concrete Pipe (CIPCP) for the proposed storm drain has been reviewed. The hydraulic analysis for the cast in place pipe was performed utilizing the flow rates provided by Stantech Consulting in their StormCAD design files dated 3/9/98. The hydraulic analysis for the preliminary design was based upon a Manning's N of 0.015 as was used in the StormCAD analysis. The invert elevations from the original design were held and the hydraulic control at the outlet was set as the pipe soffit.

A hydraulic analysis was performed utilizing the preliminary Stantech design and several alternate design modifications. The hydraulic analysis was performed using the "Water Surface Pressure Gradient" computer program developed by the Los Angeles County Department of Public Works. See the enclosed reference material for basic computational procedures and criteria.

In order to model the system one-half of the total flow rate was assumed in each barrel of a double barrel pipe system. The final design should include flow equalizing windows constructed at regular intervals to equalize flow and hydraulic gradients in both barrels of the pipe. This is particularly important, immediately upstream and downstream of the proposed junctions where significant flow enters the mainline from lateral storm drains. The preliminary plans do not indicate the details of the junctions and transitions in the system where lateral flows will enter or where the conduit will change configuration. At this time junction losses have been assumed to occur instantaneously in pipe sections at the junction stations shown. The preliminary hydraulic analysis will have to be reviewed after more detail has been determined, regarding these junction and transition structures. A critical issue at the major junctions and transitions is the need to maintain the velocities through the structure, thereby reducing expansion, contraction, and transition losses and also reducing the junction losses calculated using the Pressure + Momentum method of analysis.

The results of the various hydraulic analysis indicates that the pipe sizes shown on the preliminary design drawings produce acceptable results (Pima1 Analysis). Principally the flow in the pipes are open channel, supercritical flow except at the outlet. The initial reaches of the pipe will flow under pressure and

create backwater upstream in the system to approximately 32+50, where a hydraulic jump will occur. Unless a larger pipe/box is proposed this condition can not be avoided. There may be a slight problem at the inlet to the lateral line at station 22+00. The hydraulic gradient in the mainline at that junction will be 1619.7 and it appears that the flow line of the natural watercourse being intercepted is approximately 1620. This inlet should be reviewed for its ability to intercept the flows. There may not be a problem since the inflow is relatively small compared to the size of the lateral pipe. If needed, is it possible to extend the inlet upstream to a higher elevation.

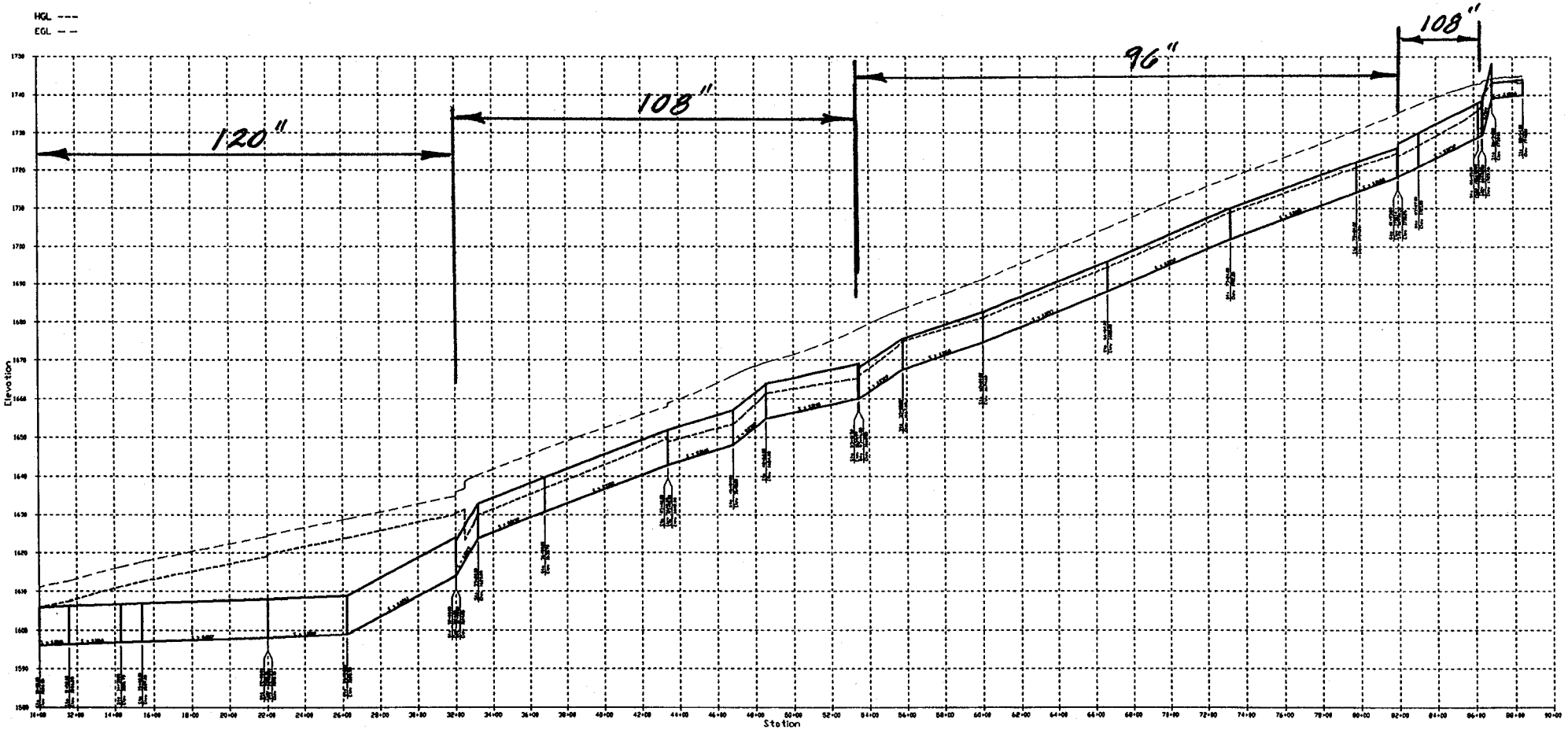
It should be noted that with CIPCP, a 114-inch diameter pipe is not an available size. For this reason a revised design was analyzed using a 108-inch diameter pipe replacing the originally specified 114-inch pipe. The hydraulic analysis for this revision (Pima2 Analysis) indicates that this change will have no significant adverse effects to the operation of the system. The use of the 108-inch diameter pipe will actually help the junction condition at station 32+00. The smaller diameter pipe on the upstream side of the junction increases the upstream momentum. This will in turn decrease the hydraulic losses in the junction and produce a hydraulic gradient at the junction approximately 1.0 foot lower than that with the 114-inch diameter pipe.

A third alternate was reviewed where the system between stations 53+44 and 81+96 has been reduced from the original 108-inch diameter pipe to 96-inch diameter pipe (Pima3 Analysis). With this alternate the flow in this reach of the system will remain supercritical, open channel flow. The most critical section with this change is the reach between 55+80 and 60+04. In this reach the normal depth of flow would be subcritical, pressure flow and a hydraulic jump would be expected upstream, but there is sufficient energy upstream to wash out the potential jump. It should be noted that with the use of a lower Manning's value, the normal depth of flow in this reach may remain supercritical, open channel flow. If this reach could be steepened to approximately 2 percent, or as much as possible, this potential could be eliminated or at least reduced.

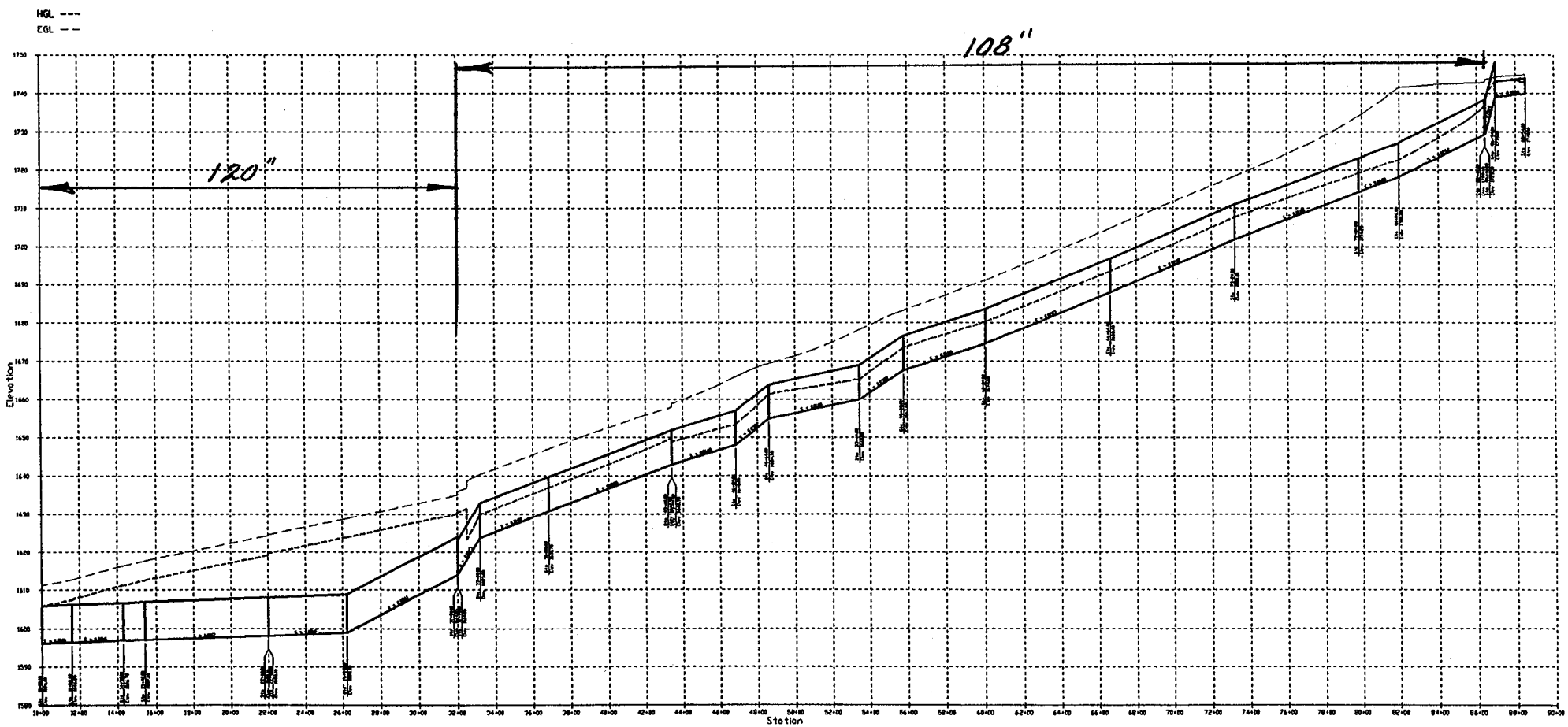
A fourth analysis (Pima4) was prepared using a more detailed analysis of the major junction at station 32+00 and the upstream transition to the existing box culverts. This analysis includes expansion and contraction losses to represent the assumed rectangular chambers created at the junction. With this analysis the

pressure + momentum at the junction changes causing the hydraulic gradient at the junction itself, to be approximately 1.6 feet higher than the previously assumed instantaneously junction. This analysis more accurately models the junction assuming the double barrel pipes are transitioned to rectangular chambers at the junction. It is unclear how the junction at the upstream end of the project near the transition to the existing multi-barreled box culverts will be configured. When this is determined the hydraulic's in this area can be reviewed. Presently we have assumed there would be separate, triple barreled boxes, transitioned to a 108-inch diameter pipe and then a junction downstream.

It is unclear how the lateral storm drain, Line P-16, operates. The proposed hydraulic gradient at the junction with the mainline will be the hydraulic control for this lateral. With all of the various analysis described above, the hydraulic gradient at the junction will be between 1630.4 to 1632.0. With this downstream control, this lateral will be flowing under pressure to the inlet. With the proposed double 66-inch pipes the friction slope in the pipe will be approximately 0.005. The hydraulic gradient, in the pipe, at the entrance may be as high as 1634.0, based upon the junction control from the Pima4 analysis. The inlet should be reviewed to determine its ability to accept the anticipated flows. The ground or rim elevation near the inlet is shown as 1638.5, but it is unclear how the flows enter the system at this point.



PIMA 3



PIMA 2

STORM DRAIN ANALYSIS PLUS

Original version by Los Angeles County Public Works
Portions Copyrighted by CIVILSOFT, 1986, 1987, 1989

Version 1.20
Serial Number 07010175

Mar 22, 1998 10:25:56

Input file : PIMA1.DAT
Output file: PIMA1.OUT

INPUT FILE LISTING

```
T1 PIMA ROAD COLLECTOR CHANNEL  -  DOUBLE BARREL PIPE,  w/ ½ Q IN EACH PIPE
T2 100-YEAR FREQUENCY,  w/ OUTLET CONDITION = HGL @ SOFFIT,   ORIGINAL DESIGN
T3 PREPARED BY:     TERRAIN ENGINEERING                 (PIMA1)    3/21/98
S    1000.001596.00120      015                 1606.00
P    1158.001596.29120      015
R    1430.001596.79120      015                                  76.0
R    1540.001597.00120      015                                            1
P    2200.001598.10120      015
J    2200.001598.10120 54   015     39.5        1500.85          30.0
R    2620.001598.90120      015                                            1
R    3200.001614.05120      015                                  40.0
J    3200.001614.05114 66   015    203.00       1616.30          30.0
P    3320.001623.80114      015                                  40.0
R    3680.001630.70114      015                                            1
P    4340.001642.90114      015
J    4340.001642.90108 60   015     63.0        1645.15          30.0
R    4684.001648.00108      015                                            1
R    4860.001654.90108      015
P    5344.001660.00108      015                                            1
P    5580.001667.60108      015
R    6004.001674.60108      015                                            1
R    6664.001688.00108      015                                            1
P    7324.001702.00108      015                                            1
P    7984.001714.20108      015                                            1
R    8196.001718.20108      015
P    8640.001729.40108      005
J    8644.001729.50108 66   015    109.0        1631.25          30.00
T    8694.001739.10  1      015
R    8854.001740.00  1      015
SU                   1      015
```

SP

WATER SURFACE PROFILE - CHANNEL DEFINITION LISTING

RD CODE	SECT NO	CHN TYPE	NO OF PIERS	AVE PIER WIDTH	HEIGHT 1 DIAMETER	BASE WIDTH	ZL	ZR	INV DROP	Y(1)	Y(2)	Y(3)	Y(4)	Y(5)	Y(6)	Y(7)	Y(8)	Y(9)	Y(10)
	1	3	2	.75	4.00	31.50	.00	.00	.00										
	54	4			4.50														
CD	60	4			5.00														
CD	66	4			5.50														
	108	4			9.00														
	114	4			9.50														
CD	120	4			10.00														

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO   1 IS A SYSTEM OUTLET      *         *     *
                U/S DATA   STATION    INVERT  SECT                                W S ELEV
                            1000.00 1596.00  120                                  1606.00

ELEMENT NO   2 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            1158.00 1596.29  120              .015                            .00    .00     .00     0

ELEMENT NO   3 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            1430.00 1596.79  120              .015                            .00  76.00     .00     0

ELEMENT NO   4 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            1540.00 1597.00  120              .015                            .00    .00     .00     1

ELEMENT NO   5 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            2200.00 1598.10  120              .015                            .00    .00     .00     0

ELEMENT NO   6 IS A JUNCTION           *         *     *     *                *                  *                *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            2200.00 1598.10  120    54     0   .015    39.5       .0  1500.85      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO   7 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            2620.00 1598.90  120              .015                            .00    .00     .00     1

ELEMENT NO   8 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            3200.00 1614.05  120              .015                            .00  40.00     .00     0

ELEMENT NO   9 IS A JUNCTION           *         *     *     *                *                  *                *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            3200.00 1614.05  114    66     0   .015   203.0       .0  1616.30      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  10 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                            3320.00 1623.80  114              .015                            .00  40.00     .00     0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  11 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           3680.00 1630.70  114              .015                                  .00    .00     .00      1

ELEMENT NO  12 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           4340.00 1642.90  114              .015                                  .00    .00     .00      0

ELEMENT NO  13 IS A JUNCTION       *        *    *    *                *                  *              *
               U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                           4340.00 1642.90  108    60     0   .015     63.0       .0  1645.15      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  14 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           4684.00 1648.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  15 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           4860.00 1654.90  108              .015                                  .00    .00     .00      0

ELEMENT NO  16 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           5344.00 1660.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  17 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           5580.00 1667.60  108              .015                                  .00    .00     .00      0

ELEMENT NO  18 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           6004.00 1674.60  108              .015                                  .00    .00     .00      1

ELEMENT NO  19 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           6664.00 1688.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  20 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           7324.00 1702.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  21 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           7984.00 1714.20  108              .015                                  .00    .00     .00      1

ELEMENT NO  22 IS A REACH          *        *    *
               U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                           8196.00 1718.20  108              .015                                  .00    .00     .00      0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  23 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8640.00 1729.40  108              .005                                  .00    .00     .00      0

ELEMENT NO  24 IS A JUNCTION         *        *    *    *               *                 *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2  N      Q3      Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            8644.00 1729.50  108    66     0  .015   109.0      .0  1631.25      .00  30.00     .00

ELEMENT NO  25 IS A TRANSITION       *        *    *
                U/S DATA   STATION    INVERT  SECT              N
                            8694.00 1739.10    1              .015

ELEMENT NO  26 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8854.00 1740.00    1              .015                                  .00    .00     .00      0

ELEMENT NO  27 IS A SYSTEM HEADWORKS                 *                    *
                U/S DATA   STATION    INVERT  SECT                                   W S ELEV
                            8854.00 1740.00    1                                        .00
NO EDIT ERRORS ENCOUNTERED-COMPUTATION IS NOW BEGINNING

** WARNING NO. 2 ** - WATER SURFACE ELEVATION GIVEN IS LESS THAN OR EQUALS INVERT ELEVATION IN HDWKDS, W.S.ELEV = INV + DC
```

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
1000.00	1596.00	10.00	1606.00	1431.0	18.22	5.16	1611.16	.00	8.88		10.00	.00	.00	0	.00
158.00	.00184					.00997	1.58			10.00			.00		
1158.00	1596.29	11.29	1607.58	1431.0	18.22	5.16	1612.73	.00	8.88		10.00	.00	.00	0	.00
272.00	.00184					.00997	2.71			10.00			.00		
1430.00	1596.79	14.44	1611.23	1431.0	18.22	5.16	1616.39	.00	8.88		10.00	.00	.00	0	.00
110.00	.00191					.00997	1.10			10.00			.00		
1540.00	1597.00	15.59	1612.59	1431.0	18.22	5.16	1617.75	.00	8.88		10.00	.00	.00	0	.00
660.00	.00167					.00997	6.58			10.00			.00		
2200.00	1598.10	21.07	1619.17	1431.0	18.22	5.16	1624.33	.00	8.88		10.00	.00	.00	0	.00
JUNCT STR	.00000					.00970	.00						.00		
2200.00	1598.10	21.60	1619.70	1391.5	17.72	4.88	1624.58	.00	8.80		10.00	.00	.00	0	.00
420.00	.00190					.00943	3.96			10.00			.00		
2620.00	1598.90	25.00	1623.90	1391.5	17.72	4.88	1628.78	.00	8.80		10.00	.00	.00	0	.00
580.00	.02612					.00943	5.47			5.59			.00		
3200.00	1614.05	15.97	1630.02	1391.5	17.72	4.88	1634.90	.00	8.80		10.00	.00	.00	0	.00
JUNCT STR	.00000					.00923	.00						.00		
3200.00	1614.05	17.31	1631.36	1188.5	16.77	4.37	1635.73	.00	8.26		9.50	.00	.00	0	.00
60.44	.08125					.00904	.55			3.78			.00		
3260.44	1618.96	13.24	1632.20	1188.5	16.77	4.37	1636.57	.00	8.26		9.50	.00	.00	0	.00
HYDRAULIC JUMP													.00		
3260.44	1618.96	5.08	1624.04	1188.5	30.80	14.75	1638.79	.00	8.26		9.50	.00	.00	0	.00
10.26	.08125					.02807	.29			3.78			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE

100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN

PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
3270.70	1619.79	5.17	1624.96	1188.5	30.14	14.12	1639.09	.00	8.26		9.50	.00	.00	0	.00
19.43	.08125					.02567	.50			3.78			.00		
3290.13	1621.37	5.37	1626.75	1188.5	28.74	12.84	1639.58	.00	8.26		9.50	.00	.00	0	.00
16.25	.08125					.02268	.37			3.78			.00		
3306.38	1622.69	5.59	1628.28	1188.5	27.40	11.67	1639.95	.00	8.26		9.50	.00	.00	0	.00
13.62	.08125					.02006	.27			3.78			.00		
3320.00	1623.80	5.82	1629.62	1188.5	26.13	10.61	1640.23	.00	8.26		9.50	.00	.00	0	.00
360.00	.01917					.01846	6.65			5.78			.00		
3680.00	1630.70	5.90	1636.60	1188.5	25.71	10.28	1646.87	.00	8.26		9.50	.00	.00	0	.00
.00	.01917					.01809	.00			5.78			.00		
3680.00	1630.70	5.90	1636.60	1188.5	25.71	10.28	1646.87	.00	8.26		9.50	.00	.00	0	.00
457.76	.01849					.01725	7.90			5.85			.00		
4137.75	1639.16	6.09	1645.26	1188.5	24.74	9.51	1654.77	.00	8.26		9.50	.00	.00	0	.00
202.25	.01849					.01549	3.13			5.85			.00		
4340.00	1642.90	6.35	1649.25	1188.5	23.59	8.65	1657.90	.00	8.26		9.50	.00	.00	0	.00
JUNCT STR	.00000					.01636	.00						.00		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
JUNCT STR	.00000					.01814	.00						.00		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
85.60	.01483					.01864	1.60			6.40			.00		
4425.60	1644.17	5.82	1649.99	1125.5	25.84	10.38	1660.37	.00	8.06		9.00	.00	.00	0	.00
145.23	.01483					.02036	2.96			6.40			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
4570.83	1646.32	5.59	1651.91	1125.5	27.10	11.42	1663.33	.00	8.06		9.00	.00	.00	0	.00
113.17	.01483					.02297	2.60			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
.00	.01483					.02437	.00			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
52.21	.03920					.02310	1.21			4.63			.00		
4736.21	1650.05	5.57	1655.62	1125.5	27.23	11.52	1667.13	.00	8.06		9.00	.00	.00	0	.00
43.80	.03920					.02059	.90			4.63			.00		
4780.01	1651.76	5.80	1657.57	1125.5	25.96	10.47	1668.04	.00	8.06		9.00	.00	.00	0	.00
33.65	.03920					.01828	.62			4.63			.00		
4813.66	1653.08	6.05	1659.13	1125.5	24.75	9.52	1668.65	.00	8.06		9.00	.00	.00	0	.00
26.13	.03920					.01627	.43			4.63			.00		
4839.79	1654.11	6.32	1660.42	1125.5	23.60	8.65	1669.08	.00	8.06		9.00	.00	.00	0	.00
20.21	.03920					.01452	.29			4.63			.00		
4860.00	1654.90	6.60	1661.50	1125.5	22.50	7.87	1669.37	.00	8.06		9.00	.00	.00	0	.00
17.33	.01054					.01380	.24			7.49			.00		
4877.33	1655.08	6.57	1661.65	1125.5	22.64	7.96	1669.61	.00	8.06		9.00	.00	.00	0	.00
122.02	.01054					.01473	1.80			7.49			.00		
4999.35	1656.37	6.28	1662.65	1125.5	23.74	8.76	1671.41	.00	8.06		9.00	.00	.00	0	.00
102.63	.01054					.01651	1.69			7.49			.00		
5101.99	1657.45	6.02	1663.47	1125.5	24.90	9.64	1673.10	.00	8.06		9.00	.00	.00	0	.00
89.44	.01054					.01856	1.66			7.49			.00		

WATER SURFACE PROFILE LISTING
PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
5191.43	1658.39	5.77	1664.16	1125.5	26.12	10.60	1674.76	.00	8.06		9.00	.00	.00	0	.00
79.91	.01054					.02091	1.67			7.49			.00		
5271.34	1659.23	5.54	1664.77	1125.5	27.39	11.66	1676.43	.00	8.06		9.00	.00	.00	0	.00
72.66	.01054					.02360	1.71			7.49			.00		
5344.00	1660.00	5.32	1665.32	1125.5	28.73	12.82	1678.15	.00	8.06		9.00	.00	.00	0	.00
109.54	.03220					.02362	2.59			4.92			.00		
5453.54	1663.53	5.54	1669.07	1125.5	27.40	11.67	1680.74	.00	8.06		9.00	.00	.00	0	.00
73.75	.03220					.02094	1.54			4.92			.00		
5527.29	1665.90	5.77	1671.67	1125.5	26.13	10.61	1682.28	.00	8.06		9.00	.00	.00	0	.00
52.71	.03220					.01858	.98			4.92			.00		
5580.00	1667.60	6.01	1673.61	1125.5	24.91	9.64	1683.26	.00	8.06		9.00	.00	.00	0	.00
142.95	.01651					.01776	2.54			6.14			.00		
5722.95	1669.96	5.95	1675.91	1125.5	25.23	9.89	1685.80	.00	8.06		9.00	.00	.00	0	.00
281.05	.01651					.01917	5.39			6.14			.00		
6004.00	1674.60	5.71	1680.31	1125.5	26.46	10.88	1691.19	.00	8.06		9.00	.00	.00	0	.00
6.50	.02030					.02031	.13			5.71			.00		
6010.50	1674.73	5.71	1680.44	1125.5	26.46	10.88	1691.32	.00	8.06		9.00	.00	.00	0	.00
653.50	.02030					.02076	13.57			5.71			.00		
6664.00	1688.00	5.62	1693.62	1125.5	26.92	11.26	1704.88	.00	8.06		9.00	.00	.00	0	.00
660.00	.02121					.02061	13.60			5.62			.00		
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06		9.00	.00	.00	0	.00
.00	.02121					.02001	.00			5.62			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06		9.00	.00	.00	0	.00
168.67	.01849					.02053	3.46			5.90			.00		
7492.67	1705.12	5.64	1710.75	1125.5	26.84	11.20	1721.95	.00	8.06		9.00	.00	.00	0	.00
228.19	.01849					.02241	5.11			5.90			.00		
7720.86	1709.34	5.41	1714.75	1125.5	28.15	12.32	1727.07	.00	8.06		9.00	.00	.00	0	.00
149.41	.01849					.02532	3.78			5.90			.00		
7870.27	1712.10	5.20	1717.30	1125.5	29.53	13.55	1730.85	.00	8.06		9.00	.00	.00	0	.00
113.73	.01849					.02865	3.26			5.90			.00		
7984.00	1714.20	5.01	1719.21	1125.5	30.97	14.90	1734.11	.00	8.06		9.00	.00	.00	0	.00
47.18	.01887					.03133	1.48			5.85			.00		
8031.18	1715.09	4.92	1720.01	1125.5	31.66	15.58	1735.59	.00	8.06		9.00	.00	.00	0	.00
88.46	.01887					.03440	3.04			5.85			.00		
8119.64	1716.76	4.73	1721.49	1125.5	33.21	17.14	1738.63	.00	8.06		9.00	.00	.00	0	.00
76.36	.01887					.03902	2.98			5.85			.00		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06		9.00	.00	.00	0	.00
-.00	.01887					.02305	.00			5.85			.00		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06		9.00	.00	.00	0	.00
.89	.02523					.00461	.00			2.86			.00		
8196.89	1718.22	4.56	1722.78	1125.5	34.81	18.83	1741.61	.00	8.06		9.00	.00	.00	0	.00
73.56	.02523					.00433	.32			2.86			.00		
8270.46	1720.08	4.73	1724.81	1125.5	33.19	17.12	1741.93	.00	8.06		9.00	.00	.00	0	.00
64.11	.02523					.00382	.24			2.86			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8334.57	1721.70	4.92	1726.61	1125.5	31.65	15.56	1742.18	.00	8.06		9.00	.00	.00	0	.00
55.82	.02523					.00337	.19			2.86			.00		
8390.38	1723.10	5.11	1728.22	1125.5	30.17	14.15	1742.36	.00	8.06		9.00	.00	.00	0	.00
48.65	.02523					.00298	.14			2.86			.00		
8439.03	1724.33	5.32	1729.65	1125.5	28.77	12.86	1742.51	.00	8.06		9.00	.00	.00	0	.00
42.15	.02523					.00263	.11			2.86			.00		
8481.18	1725.39	5.53	1730.93	1125.5	27.43	11.69	1742.62	.00	8.06		9.00	.00	.00	0	.00
36.39	.02523					.00233	.08			2.86			.00		
8517.57	1726.31	5.76	1732.07	1125.5	26.15	10.63	1742.71	.00	8.06		9.00	.00	.00	0	.00
31.11	.02523					.00207	.06			2.86			.00		
8548.69	1727.10	6.01	1733.11	1125.5	24.94	9.66	1742.77	.00	8.06		9.00	.00	.00	0	.00
26.33	.02523					.00184	.05			2.86			.00		
8575.01	1727.76	6.27	1734.03	1125.5	23.78	8.79	1742.82	.00	8.06		9.00	.00	.00	0	.00
21.87	.02523					.00164	.04			2.86			.00		
8596.88	1728.31	6.56	1734.87	1125.5	22.67	7.99	1742.85	.00	8.06		9.00	.00	.00	0	.00
17.52	.02523					.00147	.03			2.86			.00		
8614.40	1728.75	6.87	1735.62	1125.5	21.62	7.26	1742.88	.00	8.06		9.00	.00	.00	0	.00
13.31	.02523					.00132	.02			2.86			.00		
8627.71	1729.09	7.21	1736.30	1125.5	20.61	6.60	1742.90	.00	8.06		9.00	.00	.00	0	.00
8.87	.02523					.00120	.01			2.86			.00		
8636.57	1729.31	7.59	1736.91	1125.5	19.65	6.00	1742.91	.00	8.06		9.00	.00	.00	0	.00
3.43	.02523					.00110	.00			2.86			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ORIGINAL DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA1) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8640.00	1729.40	8.06	1737.46	1125.5	18.73	5.45	1742.91	.00	8.06		9.00	.00	.00	0	.00
NCT STR	.02499					.00919	.04						.00		
8644.00	1729.50	10.21	1739.71	1016.5	15.98	3.97	1743.68	.00	7.77		9.00	.00	.00	0	.00
ANS STR	.19200					.00673	.34						.00		
8694.00	1739.10	4.07	1743.17	1016.5	8.52	1.13	1744.30	.00	3.29		4.00	31.50	.00	2	.75
71.14	.00563					.00464	.33			3.00			.00		
8765.14	1739.50	4.00	1743.50	1016.5	8.52	1.13	1744.63	.00	3.29		4.00	31.50	.00	2	.75
25.48	.00563					.00273	.07			3.00			.00		
8790.62	1739.64	3.81	1743.46	1016.5	8.89	1.23	1744.68	.00	3.29		4.00	31.50	.00	2	.75
21.49	.00563					.00308	.07			3.00			.00		
8812.11	1739.76	3.64	1743.40	1016.5	9.32	1.35	1744.75	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00349	.05			3.00			.00		
8827.17	1739.85	3.48	1743.33	1016.5	9.73	1.47	1744.80	.00	3.29		4.00	31.50	.00	2	.75
YDRAULIC JUMP													.00		
8827.17	1739.85	3.11	1742.96	1016.5	10.90	1.85	1744.80	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00502	.08			3.00			.00		
8842.23	1739.93	3.14	1743.07	1016.5	10.80	1.81	1744.88	.00	3.29		4.00	31.50	.00	2	.75
11.77	.00563					.00464	.05			3.00			.00		
8854.00	1740.00	3.29	1743.29	1016.5	10.29	1.65	1744.94	.00	3.29		4.00	31.50	.00	2	.75

STORM DRAIN ANALYSIS PLUS

Original version by Los Angeles County Public Works
Portions Copyrighted by CIVILSOFT, 1986, 1987, 1989

Version 1.20
Serial Number 07010175

Mar 22, 1998 10:26:23

Input file : PIMA2.DAT
Output file: PIMA2.OUT

INPUT FILE LISTING

```
T1 PIMA ROAD COLLECTOR CHANNEL  -  DOUBLE BARREL PIPE,  W/ ½ Q IN EACH PIPE
T2 100-YEAR FREQUENCY,  W/ OUTLET CONDITION = HGL @ SOFFIT,   REVISED DESIGN
T3 PREPARED BY:     TERRAIN ENGINEERING                  (PIMA2)    3/21/98
   1000.001596.00120      015                1606.00
K  1158.001596.29120      015
R  1430.001596.79120      015                                  76.0
   1540.001597.00120      015                                                1
   2200.001598.10120      015
JX 2200.001598.10120 54   015     39.5       1500.85           30.0
R  2620.001598.90120      015                                                1
   3200.001614.05120      015                                  40.0
   3200.001614.05108 66   015    203.00      1616.30           30.0
R  3320.001623.80108      015                                  40.0
R  3680.001630.70108      015                                                1
   4340.001642.90108      015
JX 4340.001642.90108 60   015     63.0       1645.15           30.0
R  4684.001648.00108      015                                                1
R  4860.001654.90108      015
   5344.001660.00108      015                                                1
K  5580.001667.60108      015
R  6004.001674.60108      015                                                1
   6664.001688.00108      015                                                1
   7324.001702.00108      015                                                1
R  7984.001714.20108      015                                                1
R  8196.001718.20108      015
   8640.001729.40108      005
   8644.001729.50108 66   015    109.0       1631.25           30.00
TS 8694.001739.10  1      015
R  8854.001740.00  1      015
S                  1      015
```

CARD CODE	SECT NO	CHN TYPE	NO OF PIERS	AVE PIER WIDTH	HEIGHT 1 DIAMETER	BASE WIDTH	ZL	ZR	INV DROP	Y(1)	Y(2)	Y(3)	Y(4)	Y(5)	Y(6)	Y(7)	Y(8)	Y(9)	Y(10)
CD	1	3	2	.75	4.00	31.50	.00	.00	.00										
CD	54	4			4.50														
CD	60	4			5.00														
CD	66	4			5.50														
CD	108	4			9.00														
CD	114	4			9.50														
CD	120	4			10.00														

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO   1 IS A SYSTEM OUTLET      *         *     *
                U/S DATA   STATION    INVERT  SECT                                W S ELEV
                            1000.00 1596.00  120                                  1606.00

ELEMENT NO   2 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            1158.00 1596.29  120              .015                  .00    .00     .00     0

ELEMENT NO   3 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            1430.00 1596.79  120              .015                  .00  76.00     .00     0

ELEMENT NO   4 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            1540.00 1597.00  120              .015                  .00    .00     .00     1

ELEMENT NO   5 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            2200.00 1598.10  120              .015                  .00    .00     .00     0

ELEMENT NO   6 IS A JUNCTION           *         *     *     *                *                *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            2200.00 1598.10  120    54     0   .015    39.5       .0  1500.85      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO   7 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            2620.00 1598.90  120              .015                  .00    .00     .00     1

ELEMENT NO   8 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            3200.00 1614.05  120              .015                  .00  40.00     .00     0

ELEMENT NO   9 IS A JUNCTION           *         *     *     *                *                *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            3200.00 1614.05  108    66     0   .015   203.0       .0  1616.30      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  10 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                            3320.00 1623.80  108              .015                  .00  40.00     .00     0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  11 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            3680.00 1630.70  108              .015                                  .00    .00     .00      1

ELEMENT NO  12 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4340.00 1642.90  108              .015                                  .00    .00     .00      0

ELEMENT NO  13 IS A JUNCTION         *         *    *    *                *                 *                *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            4340.00 1642.90  108    60     0   .015    63.0       .0  1645.15      .00  30.00     .00
E ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  14 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4684.00 1648.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  15 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4860.00 1654.90  108              .015                                  .00    .00     .00      0

ELEMENT NO  16 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5344.00 1660.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  17 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5580.00 1667.60  108              .015                                  .00    .00     .00      0

ELEMENT NO  18 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6004.00 1674.60  108              .015                                  .00    .00     .00      1

ELEMENT NO  19 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6664.00 1688.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  20 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7324.00 1702.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  21 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7984.00 1714.20  108              .015                                  .00    .00     .00      1

ELEMENT NO  22 IS A REACH            *         *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8196.00 1718.20  108              .015                                  .00    .00     .00      0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  23 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT                N                                RADIUS  ANGLE  ANG PT  MAN H
                            8640.00 1729.40  108                .005                                   .00    .00     .00      0

ELEMENT NO  24 IS A JUNCTION         *         *     *     *                 *                 *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            8644.00 1729.50  108    66     0   .015    109.0       .0  1631.25      .00  30.00     .00

ELEMENT NO  25 IS A TRANSITION       *         *     *
                U/S DATA   STATION    INVERT  SECT                N
                            8694.00 1739.10    1                .015

ELEMENT NO  26 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT                N                                RADIUS  ANGLE  ANG PT  MAN H
                            8854.00 1740.00    1                .015                                   .00    .00     .00      0

ELEMENT NO  27 IS A SYSTEM HEADWORKS                  *                     *
                U/S DATA   STATION    INVERT  SECT                                        W S ELEV
                            8854.00 1740.00    1                                               .00
NO EDIT ERRORS ENCOUNTERED-COMPUTATION IS NOW BEGINNING

 WARNING NO. 2 ** - WATER SURFACE ELEVATION GIVEN IS LESS THAN OR EQUALS INVERT ELEVATION IN HDWKDS, W.S.ELEV = INV + DC
```

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
1000.00	1596.00	10.00	1606.00	1431.0	18.22	5.16	1611.16	.00	8.88		10.00	.00	.00	0	.00
158.00	.00184					.00997	1.58			10.00			.00		
1158.00	1596.29	11.29	1607.58	1431.0	18.22	5.16	1612.73	.00	8.88		10.00	.00	.00	0	.00
272.00	.00184					.00997	2.71			10.00			.00		
1430.00	1596.79	14.44	1611.23	1431.0	18.22	5.16	1616.39	.00	8.88		10.00	.00	.00	0	.00
110.00	.00191					.00997	1.10			10.00			.00		
1540.00	1597.00	15.59	1612.59	1431.0	18.22	5.16	1617.75	.00	8.88		10.00	.00	.00	0	.00
660.00	.00167					.00997	6.58			10.00			.00		
2200.00	1598.10	21.07	1619.17	1431.0	18.22	5.16	1624.33	.00	8.88		10.00	.00	.00	0	.00
NCT STR	.00000					.00970	.00						.00		
2200.00	1598.10	21.60	1619.70	1391.5	17.72	4.88	1624.58	.00	8.80		10.00	.00	.00	0	.00
420.00	.00190					.00943	3.96			10.00			.00		
2620.00	1598.90	25.00	1623.90	1391.5	17.72	4.88	1628.78	.00	8.80		10.00	.00	.00	0	.00
580.00	.02612					.00943	5.47			5.59			.00		
3200.00	1614.05	15.97	1630.02	1391.5	17.72	4.88	1634.90	.00	8.80		10.00	.00	.00	0	.00
JUNCT STR	.00000					.01074	.00						.00		
3200.00	1614.05	16.38	1630.43	1188.5	18.68	5.42	1635.86	.00	8.20		9.00	.00	.00	0	.00
50.75	.08125					.01206	.61			3.88			.00		
3250.75	1618.17	13.18	1631.35	1188.5	18.68	5.42	1636.78	.00	8.20		9.00	.00	.00	0	.00
HYDRAULIC JUMP													.00		
3250.75	1618.17	5.18	1623.35	1188.5	31.35	15.28	1638.63	.00	8.20		9.00	.00	.00	0	.00
22.09	.08125					.02866	.63			3.88			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE

100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN

PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
3272.85	1619.97	5.39	1625.35	1188.5	29.91	13.90	1639.26	.00	8.20		9.00	.00	.00	0	.00
18.66	.08125					.02538	.47			3.88			.00		
3291.51	1621.49	5.61	1627.09	1188.5	28.52	12.64	1639.73	.00	8.20		9.00	.00	.00	0	.00
15.55	.08125					.02250	.35			3.88			.00		
3307.06	1622.75	5.84	1628.59	1188.5	27.19	11.49	1640.08	.00	8.20		9.00	.00	.00	0	.00
12.94	.08125					.01998	.26			3.88			.00		
3320.00	1623.80	6.09	1629.89	1188.5	25.92	10.44	1640.34	.00	8.20		9.00	.00	.00	0	.00
360.00	.01917					.01840	6.62			6.05			.00		
3680.00	1630.70	6.20	1636.90	1188.5	25.45	10.06	1646.96	.00	8.20		9.00	.00	.00	0	.00
.00	.01917					.01798	.00			6.05			.00		
3680.00	1630.70	6.20	1636.90	1188.5	25.45	10.06	1646.96	.00	8.20		9.00	.00	.00	0	.00
167.37	.01849					.01781	2.98			6.13			.00		
3847.37	1633.79	6.24	1640.03	1188.5	25.25	9.91	1649.94	.00	8.20		9.00	.00	.00	0	.00
347.70	.01849					.01670	5.81			6.13			.00		
4195.06	1640.22	6.52	1646.74	1188.5	24.07	9.01	1655.75	.00	8.20		9.00	.00	.00	0	.00
144.94	.01849					.01495	2.17			6.13			.00		
4340.00	1642.90	6.83	1649.73	1188.5	22.95	8.19	1657.92	.00	8.20		9.00	.00	.00	0	.00
JUNCT STR	.00000					.01614	.00						.00		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
JUNCT STR	.00000					.01814	.00						.00		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
85.60	.01483					.01864	1.60			6.40			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
4425.60	1644.17	5.82	1649.99	1125.5	25.84	10.38	1660.37	.00	8.06		9.00	.00	.00	0	.00
145.23	.01483					.02036	2.96			6.40			.00		
4570.83	1646.32	5.59	1651.91	1125.5	27.10	11.42	1663.33	.00	8.06		9.00	.00	.00	0	.00
113.17	.01483					.02297	2.60			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
.00	.01483					.02437	.00			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
52.21	.03920					.02310	1.21			4.63			.00		
4736.21	1650.05	5.57	1655.62	1125.5	27.23	11.52	1667.13	.00	8.06		9.00	.00	.00	0	.00
43.80	.03920					.02059	.90			4.63			.00		
4780.01	1651.76	5.80	1657.57	1125.5	25.96	10.47	1668.04	.00	8.06		9.00	.00	.00	0	.00
33.65	.03920					.01828	.62			4.63			.00		
4813.66	1653.08	6.05	1659.13	1125.5	24.75	9.52	1668.65	.00	8.06		9.00	.00	.00	0	.00
26.13	.03920					.01627	.43			4.63			.00		
4839.79	1654.11	6.32	1660.42	1125.5	23.60	8.65	1669.08	.00	8.06		9.00	.00	.00	0	.00
20.21	.03920					.01452	.29			4.63			.00		
4860.00	1654.90	6.60	1661.50	1125.5	22.50	7.87	1669.37	.00	8.06		9.00	.00	.00	0	.00
17.33	.01054					.01380	.24			7.49			.00		
4877.33	1655.08	6.57	1661.65	1125.5	22.64	7.96	1669.61	.00	8.06		9.00	.00	.00	0	.00
122.02	.01054					.01473	1.80			7.49			.00		
4999.35	1656.37	6.28	1662.65	1125.5	23.74	8.76	1671.41	.00	8.06		9.00	.00	.00	0	.00
102.63	.01054					.01651	1.69			7.49			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
5101.99	1657.45	6.02	1663.47	1125.5	24.90	9.64	1673.10	.00	8.06		9.00	.00	.00	0	.00
89.44	.01054					.01856	1.66			7.49			.00		
5191.43	1658.39	5.77	1664.16	1125.5	26.12	10.60	1674.76	.00	8.06		9.00	.00	.00	0	.00
79.91	.01054					.02091	1.67			7.49			.00		
5271.34	1659.23	5.54	1664.77	1125.5	27.39	11.66	1676.43	.00	8.06		9.00	.00	.00	0	.00
72.66	.01054					.02360	1.71			7.49			.00		
5344.00	1660.00	5.32	1665.32	1125.5	28.73	12.82	1678.15	.00	8.06		9.00	.00	.00	0	.00
109.54	.03220					.02362	2.59			4.92			.00		
5453.54	1663.53	5.54	1669.07	1125.5	27.40	11.67	1680.74	.00	8.06		9.00	.00	.00	0	.00
73.75	.03220					.02094	1.54			4.92			.00		
5527.29	1665.90	5.77	1671.67	1125.5	26.13	10.61	1682.28	.00	8.06		9.00	.00	.00	0	.00
52.71	.03220					.01858	.98			4.92			.00		
5580.00	1667.60	6.01	1673.61	1125.5	24.91	9.64	1683.26	.00	8.06		9.00	.00	.00	0	.00
142.95	.01651					.01776	2.54			6.14			.00		
5722.95	1669.96	5.95	1675.91	1125.5	25.23	9.89	1685.80	.00	8.06		9.00	.00	.00	0	.00
281.05	.01651					.01917	5.39			6.14			.00		
6004.00	1674.60	5.71	1680.31	1125.5	26.46	10.88	1691.19	.00	8.06		9.00	.00	.00	0	.00
6.50	.02030					.02031	.13			5.71			.00		
6010.50	1674.73	5.71	1680.44	1125.5	26.46	10.88	1691.32	.00	8.06		9.00	.00	.00	0	.00
653.50	.02030					.02076	13.57			5.71			.00		
6664.00	1688.00	5.62	1693.62	1125.5	26.92	11.26	1704.88	.00	8.06		9.00	.00	.00	0	.00
660.00	.02121					.02061	13.60			5.62			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

STATION / L/ELEM	INVERT ELEV / SO	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD / SF AVE	ENERGY GRD.EL. / HF	SUPER ELEV	CRITICAL DEPTH / NORM DEPTH	HGT/ DIA	BASE/ ID NO.	ZL / ZR	NO PIER	AVBPR
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06	9.00	.00	.00	0	.00
.00	.02121					.02001	.00		5.62			.00		
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06	9.00	.00	.00	0	.00
168.67	.01849					.02053	3.46		5.90			.00		
7492.67	1705.12	5.64	1710.75	1125.5	26.84	11.20	1721.95	.00	8.06	9.00	.00	.00	0	.00
228.19	.01849					.02241	5.11		5.90			.00		
7720.86	1709.34	5.41	1714.75	1125.5	28.15	12.32	1727.07	.00	8.06	9.00	.00	.00	0	.00
149.41	.01849					.02532	3.78		5.90			.00		
7870.27	1712.10	5.20	1717.30	1125.5	29.53	13.55	1730.85	.00	8.06	9.00	.00	.00	0	.00
113.73	.01849					.02865	3.26		5.90			.00		
7984.00	1714.20	5.01	1719.21	1125.5	30.97	14.90	1734.11	.00	8.06	9.00	.00	.00	0	.00
47.18	.01887					.03133	1.48		5.85			.00		
8031.18	1715.09	4.92	1720.01	1125.5	31.66	15.58	1735.59	.00	8.06	9.00	.00	.00	0	.00
88.46	.01887					.03440	3.04		5.85			.00		
8119.64	1716.76	4.73	1721.49	1125.5	33.21	17.14	1738.63	.00	8.06	9.00	.00	.00	0	.00
76.36	.01887					.03902	2.98		5.85			.00		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06	9.00	.00	.00	0	.00
-.00	.01887					.02305	.00		5.85			.00		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06	9.00	.00	.00	0	.00
.89	.02523					.00461	.00		2.86			.00		
8196.89	1718.22	4.56	1722.78	1125.5	34.81	18.83	1741.61	.00	8.06	9.00	.00	.00	0	.00
73.56	.02523					.00433	.32		2.86			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8270.46	1720.08	4.73	1724.81	1125.5	33.19	17.12	1741.93	.00	8.06		9.00	.00	.00	0	.00
64.11	.02523					.00382	.24			2.86			.00		
8334.57	1721.70	4.92	1726.61	1125.5	31.65	15.56	1742.18	.00	8.06		9.00	.00	.00	0	.00
55.82	.02523					.00337	.19			2.86			.00		
8390.38	1723.10	5.11	1728.22	1125.5	30.17	14.15	1742.36	.00	8.06		9.00	.00	.00	0	.00
48.65	.02523					.00298	.14			2.86			.00		
8439.03	1724.33	5.32	1729.65	1125.5	28.77	12.86	1742.51	.00	8.06		9.00	.00	.00	0	.00
42.15	.02523					.00263	.11			2.86			.00		
8481.18	1725.39	5.53	1730.93	1125.5	27.43	11.69	1742.62	.00	8.06		9.00	.00	.00	0	.00
36.39	.02523					.00233	.08			2.86			.00		
8517.57	1726.31	5.76	1732.07	1125.5	26.15	10.63	1742.71	.00	8.06		9.00	.00	.00	0	.00
31.11	.02523					.00207	.06			2.86			.00		
8548.69	1727.10	6.01	1733.11	1125.5	24.94	9.66	1742.77	.00	8.06		9.00	.00	.00	0	.00
26.33	.02523					.00184	.05			2.86			.00		
8575.01	1727.76	6.27	1734.03	1125.5	23.78	8.79	1742.82	.00	8.06		9.00	.00	.00	0	.00
21.87	.02523					.00164	.04			2.86			.00		
8596.88	1728.31	6.56	1734.87	1125.5	22.67	7.99	1742.85	.00	8.06		9.00	.00	.00	0	.00
17.52	.02523					.00147	.03			2.86			.00		
8614.40	1728.75	6.87	1735.62	1125.5	21.62	7.26	1742.88	.00	8.06		9.00	.00	.00	0	.00
13.31	.02523					.00132	.02			2.86			.00		
8627.71	1729.09	7.21	1736.30	1125.5	20.61	6.60	1742.90	.00	8.06		9.00	.00	.00	0	.00
8.87	.02523					.00120	.01			2.86			.00		

WATER SURFACE PROFILE LISTING
PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, REVISED DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA2) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8636.57	1729.31	7.59	1736.91	1125.5	19.65	6.00	1742.91	.00	8.06		9.00	.00	.00	0	.00
3.43	.02523					.00110	.00			2.86			.00		
8640.00	1729.40	8.06	1737.46	1125.5	18.73	5.45	1742.91	.00	8.06		9.00	.00	.00	0	.00
CT STR	.02499					.00919	.04						.00		
8644.00	1729.50	10.21	1739.71	1016.5	15.98	3.97	1743.68	.00	7.77		9.00	.00	.00	0	.00
NS STR	.19200					.00673	.34						.00		
8694.00	1739.10	4.07	1743.17	1016.5	8.52	1.13	1744.30	.00	3.29		4.00	31.50	.00	2	.75
71.14	.00563					.00464	.33			3.00			.00		
8765.14	1739.50	4.00	1743.50	1016.5	8.52	1.13	1744.63	.00	3.29		4.00	31.50	.00	2	.75
25.48	.00563					.00273	.07			3.00			.00		
8790.62	1739.64	3.81	1743.46	1016.5	8.89	1.23	1744.68	.00	3.29		4.00	31.50	.00	2	.75
21.49	.00563					.00308	.07			3.00			.00		
8812.11	1739.76	3.64	1743.40	1016.5	9.32	1.35	1744.75	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00349	.05			3.00			.00		
8827.17	1739.85	3.48	1743.33	1016.5	9.73	1.47	1744.80	.00	3.29		4.00	31.50	.00	2	.75
HYDRAULIC JUMP													.00		
8827.17	1739.85	3.11	1742.96	1016.5	10.90	1.85	1744.80	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00502	.08			3.00			.00		
8842.23	1739.93	3.14	1743.07	1016.5	10.80	1.81	1744.88	.00	3.29		4.00	31.50	.00	2	.75
11.77	.00563					.00464	.05			3.00			.00		
8854.00	1740.00	3.29	1743.29	1016.5	10.29	1.65	1744.94	.00	3.29		4.00	31.50	.00	2	.75

STORM DRAIN ANALYSIS PLUS

Original version by Los Angeles County Public Works
Portions Copyrighted by CIVILSOFT, 1986, 1987, 1989

Version 1.20
Serial Number 07010175

Mar 22, 1998 10:27:33

Input file : PIMA3.DAT
Output file: PIMA3.OUT

INPUT FILE LISTING

```
T1 PIMA ROAD COLLECTOR CHANNEL  -  DOUBLE BARREL PIPE,  w/ ½ Q IN EACH PIPE
T2 100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT,  ALTERNATE DESIGN
   PREPARED BY:     TERRAIN ENGINEERING                  (PIMA3)    3/21/98
     1000.001596.00120      015                1606.00
R    1158.001596.29120      015
R    1430.001596.79120      015                                  76.0
     1540.001597.00120      015                                                1
     2200.001598.10120      015
JX   2200.001598.10120 54   015     39.5       1500.85          30.0
R    2620.001598.90120      015                                                1
     3200.001614.05120      015                                  40.0
JX   3200.001614.05108 66   015    203.00      1616.30          30.0
R    3320.001623.80108      015                                  40.0
     3680.001630.70108      015                                                1
     4340.001642.90108      015
JX   4340.001642.90108 60   015     63.0       1645.15          30.0
R    4684.001648.00108      015                                                1
     4860.001654.90108      015
     5341.501659.97108      015
TS   5346.501660.08 96      015
R    5580.001667.60 96      015
     6004.001674.60 96      015                                                1
     6664.001688.00 96      015                                                1
R    7324.001702.00 96      015                                                1
R    7984.001714.20 96      015
     8193.501718.14 96      015
     8198.501718.26108      015
R    8307.001721.00108      015
R    8621.001728.92108      015                                  90.00
     8640.001729.40108      005
JX   8644.001729.50108 66   015    109.0       1631.25          30.00
TS   8694.001739.10  1      015
     8854.001740.00  1      015
                     1      015
```

RD CODE	SECT NO	CHN TYPE	NO OF PIERS	AVE PIER WIDTH	HEIGHT 1 DIAMETER	BASE WIDTH	ZL	ZR	INV DROP	Y(1)	Y(2)	Y(3)	Y(4)	Y(5)	Y(6)	Y(7)	Y(8)	Y(9)	Y(10)
	1	3	2	.75	4.00	31.50	.00	.00	.00										
	54	4			4.50														
CD	60	4			5.00														
CD	66	4			5.50														
	96	4			8.00														
	108	4			9.00														
CD	114	4			9.50														
CD	120	4			10.00														

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO   1 IS A SYSTEM OUTLET     *         *     *
                U/S DATA   STATION    INVERT  SECT                                W S ELEV
                             1000.00 1596.00  120                                  1606.00

ELEMENT NO   2 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             1158.00 1596.29  120              .015                            .00    .00     .00      0

ELEMENT NO   3 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             1430.00 1596.79  120              .015                            .00  76.00     .00      0

ELEMENT NO   4 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             1540.00 1597.00  120              .015                            .00    .00     .00      1

ELEMENT NO   5 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             2200.00 1598.10  120              .015                            .00    .00     .00      0

ELEMENT NO   6 IS A JUNCTION          *         *     *     *                 *                 *                 *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                             2200.00 1598.10  120    54     0  .015    39.5       .0  1500.85      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO   7 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             2620.00 1598.90  120              .015                            .00    .00     .00      1

ELEMENT NO   8 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             3200.00 1614.05  120              .015                            .00  40.00     .00      0

ELEMENT NO   9 IS A JUNCTION          *         *     *     *                 *                 *                 *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                             3200.00 1614.05  108    66     0  .015   203.0       .0  1616.30      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  10 IS A REACH             *         *     *
                U/S DATA   STATION    INVERT  SECT              N                          RADIUS  ANGLE  ANG PT  MAN H
                             3320.00 1623.80  108              .015                            .00  40.00     .00      0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  11 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            3680.00 1630.70  108              .015                                  .00    .00     .00     1

ELEMENT NO  12 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4340.00 1642.90  108              .015                                  .00    .00     .00     0

ELEMENT NO  13 IS A JUNCTION         *        *     *     *                *                  *                *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            4340.00 1642.90  108    60     0   .015     63.0       .0  1645.15      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  14 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4684.00 1648.00  108              .015                                  .00    .00     .00     1

ELEMENT NO  15 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4860.00 1654.90  108              .015                                  .00    .00     .00     0

ELEMENT NO  16 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5341.50 1659.97  108              .015                                  .00    .00     .00     0

ELEMENT NO  17 IS A TRANSITION       *        *     *
                U/S DATA   STATION    INVERT  SECT              N
                            5346.50 1660.08   96              .015

ELEMENT NO  18 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5580.00 1667.60   96              .015                                  .00    .00     .00     0

ELEMENT NO  19 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6004.00 1674.60   96              .015                                  .00    .00     .00     1

ELEMENT NO  20 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6664.00 1688.00   96              .015                                  .00    .00     .00     1

ELEMENT NO  21 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7324.00 1702.00   96              .015                                  .00    .00     .00     1

ELEMENT NO  22 IS A REACH            *        *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7984.00 1714.20   96              .015                                  .00    .00     .00     0
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  23 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8193.50 1718.14   96              .015                                  .00    .00     .00      0

ELEMENT NO  24 IS A TRANSITION       *        *    *
                U/S DATA   STATION    INVERT  SECT              N
                            8198.50 1718.26  108              .015

ELEMENT NO  25 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8307.00 1721.00  108              .015                                  .00    .00     .00      0

ELEMENT NO  26 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8621.00 1728.92  108              .015                                  .00  90.00     .00      0

ELEMENT NO  27 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8640.00 1729.40  108              .005                                  .00    .00     .00      0

ELEMENT NO  28 IS A JUNCTION         *        *    *    *                *                 *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2  N      Q3      Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            8644.00 1729.50  108    66     0  .015    109.0      .0  1631.25      .00  30.00     .00

ELEMENT NO  29 IS A TRANSITION       *        *    *
                U/S DATA   STATION    INVERT  SECT              N
                            8694.00 1739.10    1              .015

ELEMENT NO  30 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8854.00 1740.00    1              .015                                  .00    .00     .00      0

ELEMENT NO  31 IS A SYSTEM HEADWORKS                 *                    *
                U/S DATA   STATION    INVERT  SECT                                   W S ELEV
                            8854.00 1740.00    1                                        .00
NO EDIT ERRORS ENCOUNTERED-COMPUTATION IS NOW BEGINNING

 WARNING NO. 2 ** - WATER SURFACE ELEVATION GIVEN IS LESS THAN OR EQUALS INVERT ELEVATION IN HDWKDS, W.S.ELEV = INV + DC
```

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
1000.00	1596.00	10.00	1606.00	1431.0	18.22	5.16	1611.16	.00	8.88		10.00	.00	.00	0	.00
158.00	.00184					.00997	1.58			10.00			.00		
1158.00	1596.29	11.29	1607.58	1431.0	18.22	5.16	1612.73	.00	8.88		10.00	.00	.00	0	.00
272.00	.00184					.00997	2.71			10.00			.00		
1430.00	1596.79	14.44	1611.23	1431.0	18.22	5.16	1616.39	.00	8.88		10.00	.00	.00	0	.00
110.00	.00191					.00997	1.10			10.00			.00		
1540.00	1597.00	15.59	1612.59	1431.0	18.22	5.16	1617.75	.00	8.88		10.00	.00	.00	0	.00
660.00	.00167					.00997	6.58			10.00			.00		
2200.00	1598.10	21.07	1619.17	1431.0	18.22	5.16	1624.33	.00	8.88		10.00	.00	.00	0	.00
JUNCT STR	.00000					.00970	.00						.00		
2200.00	1598.10	21.60	1619.70	1391.5	17.72	4.88	1624.58	.00	8.80		10.00	.00	.00	0	.00
420.00	.00190					.00943	3.96			10.00			.00		
2620.00	1598.90	25.00	1623.90	1391.5	17.72	4.88	1628.78	.00	8.80		10.00	.00	.00	0	.00
580.00	.02612					.00943	5.47			5.59			.00		
3200.00	1614.05	15.97	1630.02	1391.5	17.72	4.88	1634.90	.00	8.80		10.00	.00	.00	0	.00
JUNCT STR	.00000					.01074	.00						.00		
3200.00	1614.05	16.38	1630.43	1188.5	18.68	5.42	1635.86	.00	8.20		9.00	.00	.00	0	.00
50.76	.08125					.01206	.61			3.88			.00		
3250.76	1618.17	13.18	1631.35	1188.5	18.68	5.42	1636.78	.00	8.20		9.00	.00	.00	0	.00
HYDRAULIC JUMP													.00		
3250.76	1618.17	5.18	1623.35	1188.5	31.35	15.28	1638.63	.00	8.20		9.00	.00	.00	0	.00
22.08	.08125					.02866	.63			3.88			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
3272.84	1619.97	5.39	1625.35	1188.5	29.91	13.90	1639.26	.00	8.20		9.00	.00	.00	0	.00
18.66	.08125					.02538	.47			3.88			.00		
3291.50	1621.48	5.61	1627.09	1188.5	28.52	12.64	1639.73	.00	8.20		9.00	.00	.00	0	.00
15.55	.08125					.02250	.35			3.88			.00		
3307.06	1622.75	5.84	1628.59	1188.5	27.19	11.49	1640.08	.00	8.20		9.00	.00	.00	0	.00
12.94	.08125					.01998	.26			3.88			.00		
3320.00	1623.80	6.09	1629.89	1188.5	25.92	10.44	1640.34	.00	8.20		9.00	.00	.00	0	.00
360.00	.01917					.01840	6.62			6.05			.00		
3680.00	1630.70	6.20	1636.90	1188.5	25.45	10.07	1646.96	.00	8.20		9.00	.00	.00	0	.00
164.21	.01849					.01782	2.93			6.13			.00		
3844.21	1633.74	6.24	1639.97	1188.5	25.26	9.91	1649.89	.00	8.20		9.00	.00	.00	0	.00
350.28	.01849					.01671	5.85			6.13			.00		
4194.48	1640.21	6.52	1646.73	1188.5	24.08	9.01	1655.74	.00	8.20		9.00	.00	.00	0	.00
145.52	.01849					.01496	2.18			6.13			.00		
4340.00	1642.90	6.82	1649.72	1188.5	22.96	8.19	1657.92	.00	8.20		9.00	.00	.00	0	.00
JUNCT STR	.00000					.01615	.00						.00		
4340.00	1642.90	5.93	1648.83	1125.5	25.29	9.94	1658.78	.00	8.06		9.00	.00	.00	0	.00
86.25	.01483					.01866	1.61			6.40			.00		
4426.25	1644.18	5.82	1650.00	1125.5	25.85	10.39	1660.39	.00	8.06		9.00	.00	.00	0	.00
144.80	.01483					.02038	2.95			6.40			.00		
4571.06	1646.33	5.59	1651.91	1125.5	27.11	11.42	1663.34	.00	8.06		9.00	.00	.00	0	.00
112.94	.01483					.02300	2.60			6.40			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
4684.00	1648.00	5.37	1653.37	1125.5	28.44	12.57	1665.94	.00	8.06		9.00	.00	.00	0	.00
51.43	.03920					.02314	1.19			4.63			.00		
4735.43	1650.02	5.56	1655.58	1125.5	27.26	11.55	1667.13	.00	8.06		9.00	.00	.00	0	.00
44.08	.03920					.02065	.91			4.63			.00		
4779.50	1651.74	5.80	1657.54	1125.5	25.99	10.50	1668.04	.00	8.06		9.00	.00	.00	0	.00
33.84	.03920					.01834	.62			4.63			.00		
4813.34	1653.07	6.04	1659.11	1125.5	24.78	9.54	1668.66	.00	8.06		9.00	.00	.00	0	.00
26.32	.03920					.01632	.43			4.63			.00		
4839.67	1654.10	6.31	1660.41	1125.5	23.63	8.67	1669.09	.00	8.06		9.00	.00	.00	0	.00
20.33	.03920					.01456	.30			4.63			.00		
4860.00	1654.90	6.60	1661.50	1125.5	22.53	7.89	1669.38	.00	8.06		9.00	.00	.00	0	.00
16.00	.01053					.01383	.22			7.49			.00		
4876.00	1655.07	6.56	1661.63	1125.5	22.65	7.97	1669.60	.00	8.06		9.00	.00	.00	0	.00
121.69	.01053					.01475	1.79			7.49			.00		
4997.70	1656.35	6.28	1662.63	1125.5	23.75	8.77	1671.40	.00	8.06		9.00	.00	.00	0	.00
102.28	.01053					.01653	1.69			7.49			.00		
5099.97	1657.43	6.01	1663.44	1125.5	24.91	9.65	1673.09	.00	8.06		9.00	.00	.00	0	.00
89.21	.01053					.01858	1.66			7.49			.00		
5189.18	1658.37	5.77	1664.13	1125.5	26.13	10.61	1674.74	.00	8.06		9.00	.00	.00	0	.00
79.83	.01053					.02094	1.67			7.49			.00		
5269.01	1659.21	5.54	1664.74	1125.5	27.41	11.67	1676.42	.00	8.06		9.00	.00	.00	0	.00
72.49	.01053					.02364	1.71			7.49			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
5341.50	1659.97	5.32	1665.29	1125.5	28.74	12.84	1678.13	.00	8.06		9.00	.00	.00	0	.00
ANS STR	.02200					.02502	.13						.00		
5346.50	1660.08	5.94	1666.02	1125.5	28.13	12.29	1678.31	.00	7.69		8.00	.00	.00	0	.00
1.85	.03221					.02495	.05			5.38			.00		
5348.35	1660.14	5.94	1666.08	1125.5	28.11	12.28	1678.36	.00	7.69		8.00	.00	.00	0	.00
97.14	.03221					.02367	2.30			5.38			.00		
5445.49	1663.27	6.23	1669.50	1125.5	26.80	11.16	1680.66	.00	7.69		8.00	.00	.00	0	.00
64.15	.03221					.02136	1.37			5.38			.00		
5509.65	1665.33	6.55	1671.88	1125.5	25.55	10.14	1682.03	.00	7.69		8.00	.00	.00	0	.00
43.45	.03221					.01947	.85			5.38			.00		
5553.09	1666.73	6.92	1673.65	1125.5	24.36	9.22	1682.87	.00	7.69		8.00	.00	.00	0	.00
26.91	.03221					.01811	.49			5.38			.00		
5580.00	1667.60	7.38	1674.98	1125.5	23.23	8.38	1683.36	.00	7.69		8.00	.00	.00	0	.00
236.57	.01651					.01810	4.28			8.00			.00		
5816.57	1671.51	6.92	1678.43	1125.5	24.35	9.22	1687.64	.00	7.69		8.00	.00	.00	0	.00
187.43	.01651					.01946	3.65			8.00			.00		
6004.00	1674.60	6.55	1681.15	1125.5	25.54	10.14	1691.29	.00	7.69		8.00	.00	.00	0	.00
660.00	.02030					.02061	13.60			6.55			.00		
6664.00	1688.00	6.45	1694.45	1125.5	25.93	10.45	1704.89	.00	7.69		8.00	.00	.00	0	.00
378.97	.02121					.02051	7.77			6.40			.00		
7042.97	1696.04	6.59	1702.62	1125.5	25.42	10.04	1712.67	.00	7.69		8.00	.00	.00	0	.00
281.03	.02121					.01930	5.42			6.40			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

TATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
7324.00	1702.00	6.96	1708.96	1125.5	24.24	9.13	1718.09	.00	7.69		8.00	.00	.00	0	.00
660.00	.01849					.01915	12.64			6.96			.00		
7984.00	1714.20	6.64	1720.84	1125.5	25.22	9.89	1730.73	.00	7.69		8.00	.00	.00	0	.00
209.50	.01881					.02028	4.25			6.87			.00		
8193.50	1718.14	6.47	1724.61	1125.5	25.83	10.37	1734.98	.00	7.69		8.00	.00	.00	0	.00
ANS STR	.02400					.02123	.11						.00		
8198.50	1718.26	5.58	1723.84	1125.5	27.16	11.47	1735.31	.00	8.06		9.00	.00	.00	0	.00
108.50	.02525					.02101	2.28			5.31			.00		
8307.00	1721.00	5.71	1726.71	1125.5	26.46	10.88	1737.59	.00	8.06		9.00	.00	.00	0	.00
.00	.02525					.02032	.00			5.31			.00		
8307.00	1721.00	5.71	1726.71	1125.5	26.46	10.88	1737.59	.00	8.06		9.00	.00	.00	0	.00
93.67	.02522					.01950	1.83			5.31			.00		
8400.67	1723.36	5.87	1729.24	1125.5	25.59	10.18	1739.42	.00	8.06		9.00	.00	.00	0	.00
88.86	.02522					.01766	1.57			5.31			.00		
8489.53	1725.60	6.13	1731.73	1125.5	24.40	9.25	1740.98	.00	8.06		9.00	.00	.00	0	.00
59.93	.02522					.01572	.94			5.31			.00		
8549.46	1727.12	6.40	1733.51	1125.5	23.27	8.41	1741.93	.00	8.06		9.00	.00	.00	0	.00
42.04	.02522					.01405	.59			5.31			.00		
8591.50	1728.18	6.69	1734.87	1125.5	22.18	7.65	1742.52	.00	8.06		9.00	.00	.00	0	.00
29.50	.02522					.01260	.37			5.31			.00		
8621.00	1728.92	7.02	1735.94	1125.5	21.15	6.95	1742.89	.00	8.06		9.00	.00	.00	0	.00
6.72	.02526					.00129	.01			2.86			.00		

WATER SURFACE PROFILE LISTING
PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ OUTLET CONDITION = HGL @ SOFFIT, ALTERNATE DESIGN
PREPARED BY: TERRAIN ENGINEERING (PIMA3) 3/21/98

ATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8627.72	1729.09	7.21	1736.30	1125.5	20.61	6.60	1742.90	.00	8.06		9.00	.00	.00	0	.00
8.86	.02526					.00120	.01			2.86			.00		
8636.58	1729.31	7.59	1736.91	1125.5	19.65	6.00	1742.91	.00	8.06		9.00	.00	.00	0	.00
3.42	.02526					.00110	.00			2.86			.00		
8640.00	1729.40	8.06	1737.46	1125.5	18.73	5.45	1742.91	.00	8.06		9.00	.00	.00	0	.00
NCT STR	.02499					.00919	.04						.00		
8644.00	1729.50	10.21	1739.71	1016.5	15.98	3.97	1743.68	.00	7.77		9.00	.00	.00	0	.00
ANS STR	.19200					.00673	.34						.00		
8694.00	1739.10	4.07	1743.17	1016.5	8.52	1.13	1744.30	.00	3.29		4.00	31.50	.00	2	.75
71.14	.00563					.00464	.33			3.00			.00		
8765.14	1739.50	4.00	1743.50	1016.5	8.52	1.13	1744.63	.00	3.29		4.00	31.50	.00	2	.75
25.48	.00563					.00273	.07			3.00			.00		
8790.62	1739.64	3.81	1743.46	1016.5	8.89	1.23	1744.68	.00	3.29		4.00	31.50	.00	2	.75
21.49	.00563					.00308	.07			3.00			.00		
8812.11	1739.76	3.64	1743.40	1016.5	9.32	1.35	1744.75	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00349	.05			3.00			.00		
8827.17	1739.85	3.48	1743.33	1016.5	9.73	1.47	1744.80	.00	3.29		4.00	31.50	.00	2	.75
HYDRAULIC JUMP													.00		
8827.17	1739.85	3.11	1742.96	1016.5	10.90	1.85	1744.80	.00	3.29		4.00	31.50	.00	2	.75
15.06	.00563					.00502	.08			3.00			.00		
8842.23	1739.93	3.14	1743.07	1016.5	10.80	1.81	1744.88	.00	3.29		4.00	31.50	.00	2	.75
11.77	.00563					.00464	.05			3.00			.00		
8854.00	1740.00	3.29	1743.29	1016.5	10.29	1.65	1744.94	.00	3.29		4.00	31.50	.00	2	.75

STORM DRAIN ANALYSIS PLUS

Original version by Los Angeles County Public Works
Portions Copyrighted by CIVILSOFT, 1986, 1987, 1989

Version 1.20
Serial Number 07010175

Mar 22, 1998 8:44:23

Input file : PIMA4.DAT
Output file: PIMA4.OUT

INPUT FILE LISTING

```
T1 PIMA ROAD COLLECTOR CHANNEL  -  DOUBLE BARREL PIPE,  w/ ½ Q IN EACH PIPE
T2 100-YEAR FREQUENCY,   w/ HGL @ SOFFIT ,   WALL EXIT & ENTRANCE
T3 PREPARED BY:     TERRAIN ENGINEERING                  (PIMA4)    3/23/98
S    1000.001596.00120      015                1606.00
R    1158.001596.29120      015
R    1430.001596.79120      015                                76.0
R    1540.001597.00120      015
R    2200.001598.10120      015                                          1
JX   2200.001598.10120 54   015     39.5       1500.85         30.0
R    2620.001598.90120      015                                          1
R    3200.001614.05120      015
W                  2        015                                40.0
R    3205.001614.45  2      015
JX   3215.001615.27  3 66   015    203.0       1616.30         30.0
R    3220.001615.67  3      015
WX                 108      015
R    3320.001623.80108      015                                40.0
R    3680.001630.70108      015                                          1
R    4340.001642.90108      015
JX   4340.001642.90108 60   015     63.0       1645.15         30.0
R    4684.001648.00108      015                                          1
R    4860.001654.90108      015
R    5344.001660.00108      015                                          1
R    5580.001667.60108      015
R    6004.001674.60108      015                                          1
R    6664.001688.00108      015                                          1
R    7324.001702.00108      015                                          1
R    7984.001714.20108      015                                          1
R    8196.001718.20108      015
R    8640.001729.40108      005
JX   8644.001729.50108 66   015    109.0       1631.25         30.00
TS   8694.001739.10  4      015
W                    1      015
R    8854.001740.00  1      015
SH                   1      015
```

ARD CODE	SECT NO	CHN TYPE	NO OF PIERS	AVE PIER WIDTH	HEIGHT 1 DIAMETER	BASE WIDTH	ZL	ZR	INV DROP	Y(1)	Y(2)	Y(3)	Y(4)	Y(5)	Y(6)	Y(7)	Y(8)	Y(9)	Y(10)
D	1	3	2	.75	4.00	31.50	.00	.00	.00										
D	2	3	0	.00	10.00	11.00	.00	.00	.00										
CD	3	3	0	.00	9.00	10.00	.00	.00	.00										
CD	4	3	0	.00	4.00	31.50	.00	.00	.00										
D	54	4			4.50														
D	60	4			5.00														
CD	66	4			5.50														
CD	108	4			9.00														
D	114	4			9.50														
D	120	4			10.00														

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO   1 IS A SYSTEM OUTLET      *         *     *
                U/S DATA   STATION    INVERT  SECT                                W S ELEV
                             1000.00 1596.00  120                                  1606.00

ELEMENT NO   2 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             1158.00 1596.29  120             .015                  .00    .00     .00     0

ELEMENT NO   3 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             1430.00 1596.79  120             .015                  .00  76.00     .00     0

ELEMENT NO   4 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             1540.00 1597.00  120             .015                  .00    .00     .00     0

ELEMENT NO   5 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             2200.00 1598.10  120             .015                  .00    .00     .00     1

ELEMENT NO   6 IS A JUNCTION           *         *     *     *              *                *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2  N      Q3       Q4   INVERT-3 INVERT-4  PHI 3   PHI 4
                             2200.00 1598.10  120    54     0  .015    39.5       .0  1500.85      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO   7 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             2620.00 1598.90  120             .015                  .00    .00     .00     1

ELEMENT NO   8 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             3200.00 1614.05  120             .015                  .00    .00     .00     0

ELEMENT NO   9 IS A  WALL  ENTRANCE                    *
                U/S DATA   STATION    INVERT  SECT             FP
                             3200.00 1614.05    2             .015

ELEMENT NO  10 IS A REACH              *         *     *
                U/S DATA   STATION    INVERT  SECT              N                RADIUS  ANGLE  ANG PT  MAN H
                             3205.00 1614.45    2             .015                  .00    .00     .00     0

ELEMENT NO  11 IS A JUNCTION           *         *     *     *              *                *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2  N      Q3       Q4   INVERT-3 INVERT-4  PHI 3   PHI 4
                             3215.00 1615.27    3    66     0  .015   203.0       .0  1616.30      .00  30.00     .00
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  12 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            3220.00 1615.67    3              .015                                  .00    .00     .00      0

ELEMENT NO  13 IS A  WALL  EXIT                      *
                U/S DATA   STATION    INVERT  SECT
                            3220.00 1615.67  108

ELEMENT NO  14 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            3320.00 1623.80  108              .015                                  .00  40.00     .00      0

ELEMENT NO  15 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            3680.00 1630.70  108              .015                                  .00    .00     .00      1

ELEMENT NO  16 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4340.00 1642.90  108              .015                                  .00    .00     .00      0

ELEMENT NO  17 IS A JUNCTION         *        *    *    *                 *                 *              *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            4340.00 1642.90  108    60     0   .015    63.0       .0  1645.15      .00  30.00     .00
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING
THE ABOVE ELEMENT CONTAINED AN INVERT ELEV WHICH WAS NOT GREATER THAN THE PREVIOUS INVERT ELEV -WARNING

ELEMENT NO  18 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4684.00 1648.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  19 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            4860.00 1654.90  108              .015                                  .00    .00     .00      0

ELEMENT NO  20 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5344.00 1660.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  21 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            5580.00 1667.60  108              .015                                  .00    .00     .00      0

ELEMENT NO  22 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6004.00 1674.60  108              .015                                  .00    .00     .00      1

ELEMENT NO  23 IS A REACH            *        *    *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            6664.00 1688.00  108              .015                                  .00    .00     .00      1
```

WATER SURFACE PROFILE - ELEMENT CARD LISTING

```
ELEMENT NO  24 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7324.00 1702.00  108              .015                                  .00    .00     .00      1

ELEMENT NO  25 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            7984.00 1714.20  108              .015                                  .00    .00     .00      1

ELEMENT NO  26 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8196.00 1718.20  108              .015                                  .00    .00     .00      0

ELEMENT NO  27 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8640.00 1729.40  108              .005                                  .00    .00     .00      0

ELEMENT NO  28 IS A JUNCTION         *         *     *     *                *                  *                *
                U/S DATA   STATION    INVERT  SECT LAT-1 LAT-2   N      Q3       Q4    INVERT-3 INVERT-4  PHI 3   PHI 4
                            8644.00 1729.50  108    66     0  .015    109.0       .0  1631.25      .00  30.00     .00

ELEMENT NO  29 IS A TRANSITION       *         *     *
                U/S DATA   STATION    INVERT  SECT              N
                            8694.00 1739.10    4              .015

ELEMENT NO  30 IS A  WALL  EXIT                     *
                U/S DATA   STATION    INVERT  SECT
                            8694.00 1739.10    1

ELEMENT NO  31 IS A REACH            *         *     *
                U/S DATA   STATION    INVERT  SECT              N                                RADIUS  ANGLE  ANG PT  MAN H
                            8854.00 1740.00    1              .015                                  .00    .00     .00      0

ELEMENT NO  32 IS A SYSTEM HEADWORKS                *                    *
                U/S DATA   STATION    INVERT  SECT                                   W S ELEV
                            8854.00 1740.00    1                                        .00
NO EDIT ERRORS ENCOUNTERED-COMPUTATION IS NOW BEGINNING

 WARNING NO. 2 ** - WATER SURFACE ELEVATION GIVEN IS LESS THAN OR EQUALS INVERT ELEVATION IN HDWKDS, W.S.ELEV = INV + DC
```

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
1000.00	1596.00	10.00	1606.00	1431.0	18.22	5.16	1611.16	.00	8.88		10.00	.00	.00	0	.00
158.00	.00184					.00997	1.58			10.00			.00		
1158.00	1596.29	11.29	1607.58	1431.0	18.22	5.16	1612.73	.00	8.88		10.00	.00	.00	0	.00
272.00	.00184					.00997	2.71			10.00			.00		
1430.00	1596.79	14.44	1611.23	1431.0	18.22	5.16	1616.39	.00	8.88		10.00	.00	.00	0	.00
110.00	.00191					.00997	1.10			10.00			.00		
1540.00	1597.00	15.33	1612.33	1431.0	18.22	5.16	1617.49	.00	8.88		10.00	.00	.00	0	.00
660.00	.00167					.00997	6.58			10.00			.00		
2200.00	1598.10	21.07	1619.17	1431.0	18.22	5.16	1624.33	.00	8.88		10.00	.00	.00	0	.00
JUNCT STR	.00000					.00970	.00						.00		
2200.00	1598.10	21.60	1619.70	1391.5	17.72	4.88	1624.58	.00	8.80		10.00	.00	.00	0	.00
420.00	.00190					.00943	3.96			10.00			.00		
2620.00	1598.90	25.00	1623.90	1391.5	17.72	4.88	1628.78	.00	8.80		10.00	.00	.00	0	.00
580.00	.02612					.00943	5.47			5.59			.00		
3200.00	1614.05	15.32	1629.37	1391.5	17.72	4.88	1634.25	.00	8.80		10.00	.00	.00	0	.00
WALL ENTRANCE													.00		
3200.00	1614.05	17.73	1631.78	1391.5	12.68	2.50	1634.28	.00	7.92		10.00	11.00	.00	0	.00
5.00	.07998					.00455	.02			2.93			.00		
3205.00	1614.45	17.36	1631.81	1391.5	12.68	2.50	1634.30	.00	7.92		10.00	11.00	.00	0	.00
JUNCT STR	.08201					.00512	.05						.00		
3215.00	1615.27	16.71	1631.98	1188.5	13.24	2.73	1634.71	.00	7.60		9.00	10.00	.00	0	.00
5.00	.08000					.00568	.03			2.85			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
3220.00	1615.67	16.34	1632.01	1188.5	13.24	2.73	1634.74	.00	7.60		9.00	10.00	.00	0	.00
WALL EXIT													.00		
3220.00	1615.67	16.34	1632.01	1188.5	18.68	5.42	1637.43	.00	8.20		9.00	.00	.00	0	.00
75.87	.08130					.01206	.92			3.88			.00		
3295.87	1621.84	11.64	1633.47	1188.5	18.68	5.42	1638.90	.00	8.20		9.00	.00	.00	0	.00
HYDRAULIC JUMP													.00		
3295.87	1621.84	5.67	1627.51	1188.5	28.16	12.32	1639.83	.00	8.20		9.00	.00	.00	0	.00
11.20	.08130					.02213	.25			3.88			.00		
3307.07	1622.75	5.84	1628.59	1188.5	27.19	11.49	1640.08	.00	8.20		9.00	.00	.00	0	.00
12.93	.08130					.01998	.26			3.88			.00		
3320.00	1623.80	6.09	1629.89	1188.5	25.92	10.44	1640.34	.00	8.20		9.00	.00	.00	0	.00
360.00	.01917					.01840	6.62			6.05			.00		
3680.00	1630.70	6.20	1636.90	1188.5	25.45	10.06	1646.96	.00	8.20		9.00	.00	.00	0	.00
.00	.01917					.01798	.00			6.05			.00		
3680.00	1630.70	6.20	1636.90	1188.5	25.45	10.06	1646.96	.00	8.20		9.00	.00	.00	0	.00
167.37	.01849					.01781	2.98			6.13			.00		
3847.37	1633.79	6.24	1640.03	1188.5	25.25	9.91	1649.94	.00	8.20		9.00	.00	.00	0	.00
347.70	.01849					.01670	5.81			6.13			.00		
4195.06	1640.22	6.52	1646.74	1188.5	24.07	9.01	1655.75	.00	8.20		9.00	.00	.00	0	.00
144.94	.01849					.01495	2.17			6.13			.00		
4340.00	1642.90	6.83	1649.73	1188.5	22.95	8.19	1657.92	.00	8.20		9.00	.00	.00	0	.00
JUNCT STR	.00000					.01614	.00						.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
NCT STR	.00000					.01814	.00						.00		
4340.00	1642.90	5.94	1648.84	1125.5	25.29	9.94	1658.77	.00	8.06		9.00	.00	.00	0	.00
85.60	.01483					.01864	1.60			6.40			.00		
4425.60	1644.17	5.82	1649.99	1125.5	25.84	10.38	1660.37	.00	8.06		9.00	.00	.00	0	.00
145.23	.01483					.02036	2.96			6.40			.00		
4570.83	1646.32	5.59	1651.91	1125.5	27.10	11.42	1663.33	.00	8.06		9.00	.00	.00	0	.00
113.17	.01483					.02297	2.60			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
.00	.01483					.02437	.00			6.40			.00		
4684.00	1648.00	5.37	1653.37	1125.5	28.43	12.56	1665.93	.00	8.06		9.00	.00	.00	0	.00
52.21	.03920					.02310	1.21			4.63			.00		
4736.21	1650.05	5.57	1655.62	1125.5	27.23	11.52	1667.13	.00	8.06		9.00	.00	.00	0	.00
43.80	.03920					.02059	.90			4.63			.00		
4780.01	1651.76	5.80	1657.57	1125.5	25.96	10.47	1668.04	.00	8.06		9.00	.00	.00	0	.00
33.65	.03920					.01828	.62			4.63			.00		
4813.66	1653.08	6.05	1659.13	1125.5	24.75	9.52	1668.65	.00	8.06		9.00	.00	.00	0	.00
26.13	.03920					.01627	.43			4.63			.00		
4839.79	1654.11	6.32	1660.42	1125.5	23.60	8.65	1669.08	.00	8.06		9.00	.00	.00	0	.00
20.21	.03920					.01452	.29			4.63			.00		
4860.00	1654.90	6.60	1661.50	1125.5	22.50	7.87	1669.37	.00	8.06		9.00	.00	.00	0	.00
17.33	.01054					.01380	.24			7.49			.00		

WATER SURFACE PROFILE LISTING
PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
4877.33	1655.08	6.57	1661.65	1125.5	22.64	7.96	1669.61	.00	8.06		9.00	.00	.00	0	.00
122.02	.01054					.01473	1.80			7.49			.00		
4999.35	1656.37	6.28	1662.65	1125.5	23.74	8.76	1671.41	.00	8.06		9.00	.00	.00	0	.00
102.63	.01054					.01651	1.69			7.49			.00		
5101.99	1657.45	6.02	1663.47	1125.5	24.90	9.64	1673.10	.00	8.06		9.00	.00	.00	0	.00
89.44	.01054					.01856	1.66			7.49			.00		
5191.43	1658.39	5.77	1664.16	1125.5	26.12	10.60	1674.76	.00	8.06		9.00	.00	.00	0	.00
79.91	.01054					.02091	1.67			7.49			.00		
5271.34	1659.23	5.54	1664.77	1125.5	27.39	11.66	1676.43	.00	8.06		9.00	.00	.00	0	.00
72.66	.01054					.02360	1.71			7.49			.00		
5344.00	1660.00	5.32	1665.32	1125.5	28.73	12.82	1678.15	.00	8.06		9.00	.00	.00	0	.00
109.54	.03220					.02362	2.59			4.92			.00		
5453.54	1663.53	5.54	1669.07	1125.5	27.40	11.67	1680.74	.00	8.06		9.00	.00	.00	0	.00
73.75	.03220					.02094	1.54			4.92			.00		
5527.29	1665.90	5.77	1671.67	1125.5	26.13	10.61	1682.28	.00	8.06		9.00	.00	.00	0	.00
52.71	.03220					.01858	.98			4.92			.00		
5580.00	1667.60	6.01	1673.61	1125.5	24.91	9.64	1683.26	.00	8.06		9.00	.00	.00	0	.00
142.95	.01651					.01776	2.54			6.14			.00		
5722.95	1669.96	5.95	1675.91	1125.5	25.23	9.89	1685.80	.00	8.06		9.00	.00	.00	0	.00
281.05	.01651					.01917	5.39			6.14			.00		
6004.00	1674.60	5.71	1680.31	1125.5	26.46	10.88	1691.19	.00	8.06		9.00	.00	.00	0	.00
6.50	.02030					.02031	.13			5.71			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION / L/ELEM	INVERT ELEV / SO	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD / SF AVE	ENERGY GRD.EL. / HF	SUPER ELEV	CRITICAL DEPTH	NORM DEPTH	HGT/ DIA	BASE/ ID NO.	ZL / ZR	NO PIER	AVBPR
6010.50	1674.73	5.71	1680.44	1125.5	26.46	10.88	1691.32	.00	8.06		9.00	.00	.00	0	.00
653.50	.02030					.02076	13.57			5.71			.00		
6664.00	1688.00	5.62	1693.62	1125.5	26.92	11.26	1704.88	.00	8.06		9.00	.00	.00	0	.00
660.00	.02121					.02061	13.60			5.62			.00		
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06		9.00	.00	.00	0	.00
.00	.02121					.02001	.00			5.62			.00		
7324.00	1702.00	5.74	1707.74	1125.5	26.30	10.75	1718.49	.00	8.06		9.00	.00	.00	0	.00
168.67	.01849					.02053	3.46			5.90			.00		
7492.67	1705.12	5.64	1710.75	1125.5	26.84	11.20	1721.95	.00	8.06		9.00	.00	.00	0	.00
228.19	.01849					.02241	5.11			5.90			.00		
7720.86	1709.34	5.41	1714.75	1125.5	28.15	12.32	1727.07	.00	8.06		9.00	.00	.00	0	.00
149.41	.01849					.02532	3.78			5.90			.00		
7870.27	1712.10	5.20	1717.30	1125.5	29.53	13.55	1730.85	.00	8.06		9.00	.00	.00	0	.00
113.73	.01849					.02865	3.26			5.90			.00		
7984.00	1714.20	5.01	1719.21	1125.5	30.97	14.90	1734.11	.00	8.06		9.00	.00	.00	0	.00
47.18	.01887					.03133	1.48			5.85			.00		
8031.18	1715.09	4.92	1720.01	1125.5	31.66	15.58	1735.59	.00	8.06		9.00	.00	.00	0	.00
88.46	.01887					.03440	3.04			5.85			.00		
8119.64	1716.76	4.73	1721.49	1125.5	33.21	17.14	1738.63	.00	8.06		9.00	.00	.00	0	.00
76.36	.01887					.03902	2.98			5.85			.00		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06		9.00	.00	.00	0	.00
-.00	.01887					.02305	.00			5.85			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8196.00	1718.20	4.56	1722.76	1125.5	34.83	18.85	1741.61	.00	8.06		9.00	.00	.00	0	.00
.89	.02523					.00461	.00			2.86			.00		
8196.89	1718.22	4.56	1722.78	1125.5	34.81	18.83	1741.61	.00	8.06		9.00	.00	.00	0	.00
73.56	.02523					.00433	.32			2.86			.00		
8270.46	1720.08	4.73	1724.81	1125.5	33.19	17.12	1741.93	.00	8.06		9.00	.00	.00	0	.00
64.11	.02523					.00382	.24			2.86			.00		
8334.57	1721.70	4.92	1726.61	1125.5	31.65	15.56	1742.18	.00	8.06		9.00	.00	.00	0	.00
55.82	.02523					.00337	.19			2.86			.00		
8390.38	1723.10	5.11	1728.22	1125.5	30.17	14.15	1742.36	.00	8.06		9.00	.00	.00	0	.00
48.65	.02523					.00298	.14			2.86			.00		
8439.03	1724.33	5.32	1729.65	1125.5	28.77	12.86	1742.51	.00	8.06		9.00	.00	.00	0	.00
42.15	.02523					.00263	.11			2.86			.00		
8481.18	1725.39	5.53	1730.93	1125.5	27.43	11.69	1742.62	.00	8.06		9.00	.00	.00	0	.00
36.39	.02523					.00233	.08			2.86			.00		
8517.57	1726.31	5.76	1732.07	1125.5	26.15	10.63	1742.71	.00	8.06		9.00	.00	.00	0	.00
31.11	.02523					.00207	.06			2.86			.00		
8548.69	1727.10	6.01	1733.11	1125.5	24.94	9.66	1742.77	.00	8.06		9.00	.00	.00	0	.00
26.33	.02523					.00184	.05			2.86			.00		
8575.01	1727.76	6.27	1734.03	1125.5	23.78	8.79	1742.82	.00	8.06		9.00	.00	.00	0	.00
21.87	.02523					.00164	.04			2.86			.00		
8596.88	1728.31	6.56	1734.87	1125.5	22.67	7.99	1742.85	.00	8.06		9.00	.00	.00	0	.00
17.52	.02523					.00147	.03			2.86			.00		

WATER SURFACE PROFILE LISTING

PIMA ROAD COLLECTOR CHANNEL - DOUBLE BARREL PIPE, w/ ½ Q IN EACH PIPE
100-YEAR FREQUENCY, w/ HGL @ SOFFIT , WALL EXIT & ENTRANCE
PREPARED BY: TERRAIN ENGINEERING (PIMA4) 3/23/98

STATION	INVERT ELEV	DEPTH OF FLOW	W.S. ELEV	Q	VEL	VEL HEAD	ENERGY GRD.EL.	SUPER ELEV	CRITICAL DEPTH		HGT/ DIA	BASE/ ID NO.	ZL	NO PIER	AVBPR
L/ELEM	SO					SF AVE	HF			NORM DEPTH			ZR		
8614.40	1728.75	6.87	1735.62	1125.5	21.62	7.26	1742.88	.00	8.06		9.00	.00	.00	0	.00
13.31	.02523					.00132	.02			2.86			.00		
8627.71	1729.09	7.21	1736.30	1125.5	20.61	6.60	1742.90	.00	8.06		9.00	.00	.00	0	.00
8.87	.02523					.00120	.01			2.86			.00		
8636.57	1729.31	7.59	1736.91	1125.5	19.65	6.00	1742.91	.00	8.06		9.00	.00	.00	0	.00
3.43	.02523					.00110	.00			2.86			.00		
8640.00	1729.40	8.06	1737.46	1125.5	18.73	5.45	1742.91	.00	8.06		9.00	.00	.00	0	.00
NCT STR	.02499					.00919	.04						.00		
8644.00	1729.50	10.21	1739.71	1016.5	15.98	3.97	1743.68	.00	7.77		9.00	.00	.00	0	.00
ANS STR	.19200					.00597	.30						.00		
8694.00	1739.10	4.16	1743.26	1016.5	8.08	1.02	1744.27	.00	3.19		4.00	31.50	.00	0	.00
WALL EXIT													.00		
8694.00	1739.10	4.16	1743.26	1016.5	8.52	1.13	1744.39	.00	3.29		4.00	31.50	.00	2	.75
159.42	.00563					.00464	.74			3.00			.00		
8853.42	1740.00	4.00	1744.00	1016.5	8.52	1.13	1745.13	.00	3.29		4.00	31.50	.00	2	.75
.58	.00563					.00255	.00			3.00			.00		
8854.00	1740.00	4.00	1744.00	1016.5	8.48	1.12	1745.11	.00	3.29		4.00	31.50	.00	2	.75

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
A. E. Bruington, Chief Engineer

2250 Alcazar Street, Los Angeles
Telephone: (213) 226-4111

P.O. Box 2418 Terminal Annex
Los Angeles, CA 90054

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.

12.4 COMPUTATIONAL PROCEDURES

Assumptions are: Steady one dimentional flow and incompressible fluids.

12.4.1 BASIC EQUATIONS OF STEADY FLOW

a) Equation of Continuity

$$A1.V1 = A2.V2 = Q$$

b) Manning's Formula (friction slope)

$$Sf = \left\{ Q\,n/[1.486\,A\,(RH)^{\frac{2}{3}}] \right\}^2$$

c) Bernoulli's Equation (open flow)

$$D2 + HV2 + \Delta L\ Sfav = D1 + HV1 + \Delta L\ So \quad \text{where } HV = V^2/2g$$

d) Bernoulli's Equation (pressure flow)

$$D2 + HV2 + \Delta L\ Sfav + Hm = D1 + HV1 + \Delta L\ So$$

where Hm is miscel. losses.

e) Angle Point Loss

$$Hapt = 0.0033\ \Theta\ HV$$

Where Θ is deflection angle in degrees. The District recommends not to exceed 6°.

f) Bend Loss

$$HB = 0.2\ HV \sqrt{\Delta/90}$$

where Δ is central angle of bend in degrees.

g) Manhole Loss

Hmh = 0.05 HV (No. MN) where No. MH is number of manholes in a reach

h) Specific Energy

$E = D + HV$

i) Pressure - Momentum

$P2 + M2 = P1 + M1 = F$

where $M = (Q)^2 / (Ag)$

j) Critical Depth Dc

Dc is the depth of flow at minimun energy, to find Dc by parabolic method see References 12.6.4 otherwise iterate for Dc in the specific energy equat.

$Ec = f(Dc) = Dc + HVC$

k) Normal Depth Dn

Dn is the depth of uniform flow and is found by iteration from Manning's formula

$A(RH)^{2/3} = f(Dn) = [Q\,n] / [1.486\,So^{1/2}]$

12.4.2 REACH ANALYSIS

a) Open Flow

Intermediate points are computed on the W.S. profile in a reach using the standard step method. The difference in velocity head between two adjacent points is held to a maximum of ten per cent.

$$\Delta L = (E2 - E1) / (So - Sfav)$$

b) Pressure Flow

$$EGL\ 1 = EGL\ 2 + Hf + Hm$$

$$D1 = EGL\ 1 - HV1 - INV.\ 1$$

If W.S. profile rises to the soffit of a conduit before the end of the reach or if the H.G.L. breaks seal before the end of the reach, minor losses are adjusted to reflect only the portion of the reach under pressure.

Super Elevation (S.E.)

Super elevation is computed in curving channels as follows:

CHAN. TYPE 1: (Trap. Sect.)

Subcritical flow: $S.E. = 1.15\ [HV/r]\ [b + D\ (ZL + ZR)]$

Supercritical flow: $S.E. = 2.6\ [HV/r]\ [b + D\ (ZL + ZR)]$

CHAN. TYPE 2: (Rect. Sect.)

Subcritical flow: $S.E. = HV\ b/r$

Supercritical flow: $S.E. = 2\ HV\ b/r$

12.4.3 TRANSITION ANALYSIS

If V2 is greater than V1 then

$Ht = 0.1\ [HV2 - HV1]$

otherwise

$Ht = 0.2\ [HV1 - HV2]$

12.4.4 JUNCTION ANALYSIS

$\triangle Y = [(Q2.V2) - (Q1.V1) - (Q3.V3.COSO3)\ (1/g)\ (1/A\ ave)] + \triangle L\ Sf\ av$

where $A\ ave = [(A1 + A2)/2]$

and $\triangle Y = D1 + \triangle H - D2$

$HJ = \triangle Y + HV1 - HV2$

12.4.6 WALL ENTRANCE ANALYSIS (Sudden Contraction)

Lower Stage Profile (U/S Control)

Find depth at the D/S end by iteration in the equation.

M2 + P2 = M1 [(A1-A1WALL) / A1] + P1 - P1 walls

where A1 wall is the area of the obstructed part of A1. And P1 wall is the pressure on the obstructed part of A1

Upper Stage Profile (D/S Control)

If the control depth is less than the conduit height find the depth at the U/S end from

M2 + P2 = M1 [(A1-A1WALL) / A1] + P1 - P1 wall

otherwise find D1 by iteration from the following equation:

D2 + HV2 + Kc ABS [HV2 - HV1] = D1 + HV1

where Kc ABS [HV2 - HV1] is the head loss at WE.

Kc = 0.5 unless given otherwise

ABS = the absolute value

12.4.7 WALL EXIT (Sudden Expansion)

Energy loss in a wall exit = 1.0 ABS [HV2 - HV1]

In WX find D1 or D2 by iteration in the following

D2 + HV2 + 1.0 ABS [HV2 - HV1] = D1 + HV1

CONCLUSIONS AND LIMITATIONS

This report is based on design and construction experience with cast-in-place earth reinforced concrete pipe, on a detailed review of the referenced Agra Earth and Environmental, Inc. Geotechnical report and on a hydraulic review using "Water Surface Pressure Gradient" program developed by Los Angeles County Department of Public Works.

From this information professional engineering judgment as to the suitability of the project soils have been made and pipe design criteria for soil weight and shear strength have been determined. These data along with a selection of an appropriate concrete strength (f'c) are utilized in the employed structural analysis program, to make the recommendation that Cast-in-Place Earth Reinforced Concrete Pipe is a suitable alternative to reinforced concrete pipe (RCP.)

If during design or construction, differing site conditions are encountered, the contractor or owner representative shall notify this firm immediately so that alternate written recommendations can be made.

The hydraulic review has been done to current concrete pipe design standards. The analysis used allows for the recommendations regarding pipe diameters and for the recommendation that Cast-in Place Concrete Pipe is a suitable alternative to RCP.

This report is applicable to City of Scottsdale Desert Greenbelt, Pima Road Three Basins (PR3B) Project as described herein and shall not be utilized for design or construction on any other site.

Field Test of 72 in.-Diameter Cast-in-Place Nonreinforced Concrete Pipe[a]

By Curtiss W. Gilley,[1] Fellow, ASCE, Lester H. Gabriel,[2] Member, ASCE, and Robert S. Standley[3]

(Reviewed by the Pipeline Division)

Abstract: Monolithic nonreinforced cast-in-place concrete pipe (CIPCP) for storm drain, sewerage, and low-head irrigation pipelines has been in existence since 1954. This is a report on a field test of 72-in. inside diameter (ID) CIPCP with less than 2 ft cover and application of live loads exceeding 2 times H20-44 standard design highway loading. The test is directed and conducted at California State University at Sacramento for California Department of Transportation. The field test confirms the analytical model for satisfactory performance of the pipe under the conditions described.

Introduction

On September 10, 1987, a contract was awarded to the Foundation of California State University at Sacramento to design and execute full-scale field testing of a 72-in.-diameter cast-in-place concrete pipe (CIPCP). The purpose of the test program was to develop evidence as to the performance of CIPCP under minimum cover when subjected to highway loads at least as high as the standard H20-44. Soil samples were taken, and soil analyses were performed. Concrete cylinders and cores were prepared and tested. Suitability of the site and the in situ soil, a moist, firm, clayey silt over silty clay, was verified by means of a test pit. Live loads (wheel load) were certified.

The 72-in. CIPCP was chosen as being the most representative size of pipe for the product, which has a size range of 24–120 in.

The CIPCP of this study is a continuous single-stage monolithic concrete casting resulting in the manufacture and installation of nonreinforced concrete pipe used for storm, sewerage, and irrigation pipelines.

The machine used for the casting process for the 72-in.-diameter CIPCP of this study is shown in Fig. 1. The process utilized fixed and movable metal forms, the latter with mechanical tampers and internal vibrators to properly place and densify the concrete.

Response of Concrete Pipe

Because of the brittle nature of the material, successful performance of structural elements of concrete requires either a low threshold (or the ab-

[a]Paper presented at the ASCE International Conference of Pipeline Design and Installation, March 27, 1990, in Las Vegas, Nevada.

[1]Civ. Engr. and Pres., Tremont Equipment Co., 6940 Tremont Rd., Dixon, CA 95620.

[2]Prof. of Civ. Engrg., California State Univ. at Sacramento, Sacramento, CA 95819-2694.

[3]Adjunct Prof., California State Univ. at Sacramento, Sacramento, CA.

Note. Discussion open until May 1, 1992. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on April 30, 1990. This paper is part of the ***Journal of Transportation Engineering***, Vol. 118, No. 1, January/February, 1992. ©ASCE, ISSN 0733-947X/92/0001-0001/$1.00 + $.15 per page. Paper No. 26533.

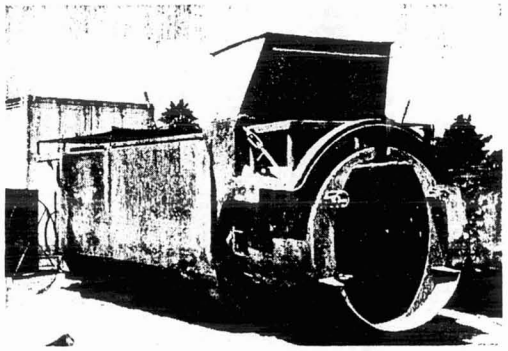


FIG. 1. 72-in. Diameter Movable Metal Form Casting Machine for Cast-in-Place Concrete Pipe

sence) of tensile stress, or the transfer of large tensile stresses from the concrete to tough, ductile fiber reinforcement of which steel reinforcement bars are the most notable example. The CIPCP of this study is an example of the former; reinforced concrete pipe (RCP) is an example of the latter.

Shear forces, in-plane thrust forces, and bending moments in the pipe wall all contribute to the stress response of the structure, when a pipe structure is resisting the application of load. For rigid structures such as concrete, secondary effects due to primary deflections are quite properly neglected; the deformed structure lies well within the bounds of small-deflection theory.

Since the stresses that arise as a consequence of the wall thrust force and the wall bending moment are both parallel and track the circumferential direction of the wall, these stresses are numerically additive. The wall thrust, due to outer wall loads, always results in compression only; the bending moment always results in both tension and compression. A properly designed and constructed CIPCP will have sufficient thrust compression stress (also known in flexible-pipe theory as "ring compression") to mask, at all points within the pipe wall, most (or all) of the flexurally induced tension stress.

To achieve this end, CIPCP is placed in the ground with passively constraining sidewalls, from approximately 25° above spring line on each side down through invert. This trench serves as forms for the casting of the concrete. See Fig. 2 for the standard section.

Any tendency for the pipe to elongate along its horizontal diameter will excite passive soil pressures in the trench walls that will create the appropriate load conditions for the reduction of the would-be bending effects. In much the same way, an arch structure develops lateral reaction thrusts that provide the same benefit. Without adequate sidewall passive capacity, this counter moment benefit may not be relied upon. Such is the case for all pipe, RCP and CIPCP included. In the case of RCP in a trench with sidewall backfill, this passive reaction is dominated by the backfill. For CIPCP, adequate sidewall passive capacity, may be expected from vertical trench-wall faces that become the external forms for the concrete pipe. The absence of tensile distress at crown and invert would be evidence of such operative passive forces in the vicinity of spring line. The test, in part, was designed

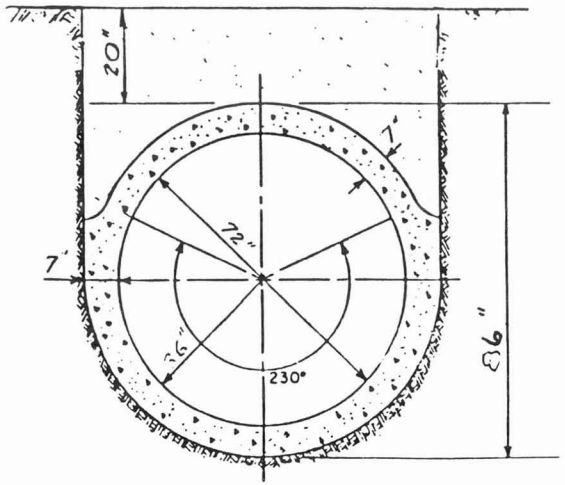


FIG. 2. Detail of Pipe Cross Section for 72-in.-Diameter CIPCP

to offer experimental evidence related to the formation and adequacy of these passive forces.

Construction

Trench excavation was completed on October 21, 1987. The trench was excavated with the special U-shaped bucket designed for 72-in. cast-in-place concrete pipe construction. The native soil at the site proved ideal for the purpose, permitting vertical trench walls with smooth-cut surfaces, and a firm uniform invert. A laser, installed at the end of the trench, was used by the tracked excavator operator to maintain line and grade using a target affixed to the bucket. Approximately 120 ft of trench bottom was finish-graded for the expected more than 80 ft of test pipe.

October 23, the pipe-casting machine was placed in the trench and secured to the winch cable at the north end of the trench. An engine in the front of the casting unit (pipe machine) provided power required to tamp and vibrate the concrete and winch the unit forward, south to north.

Transit-mix concrete (6 sack, 3,000 psi, 28-day design compressive strength, 1.5–2-in. slump, water-cement ratio of 0.49, 15% fly ash, and water reducer) was fed into a hopper, tamped, and vibrated to force the concrete down and around the steel mandrel. Smooth part-circle aluminum forms were placed inside to support the top two-thirds of the pipe. These 4-ft-long sections are fed through the casting machine just before the wet concrete emerges from the extruder. A workman behind the machine finish-troweled the exposed lower portion of the pipe (invert) as it was exposed.

Concrete was delivered in five transit-mix trucks. Test cylinders were taken from the first four trucks. (The last truck's concrete was not in a significant location.) Concrete from trucks 1–4 covered stations 0–12, 12–30, 30–48, and 48–66, respectively. The test section was at station 48 and therefore, used concrete from truckload No. 3. The concrete cylinder breaks for all cylinders tested ranged from 3,830 psi to 3,900 psi at the 28-day breaks.

Construction Load Tests

On October 26, test-cylinder breaks were made. The 72-hr compression strengths were 2,300–2,450 psi. Attainment of 2,000 psi strength is an established guideline for starting backfilling operations. Since this was met, backfilling was started south of the test section (station 48) from stations 0–30. The purpose was to demonstrate the pipe's ability to handle construction equipment and backfill dead loads at 2,000 psi compression strength. Native soil, a silty clay from the trench, was placed in lifts and compacted with a vibrating sheeps-foot roller to 20 in. of the pipe crown to relative density of 92.2% Caltrans test standard. A temporary crossing for the test load was graded at stations 12–20. A loaded gravel truck was driven across five times and then parked directly over the pipe for 15 minutes (Fig. 3). The pipe interior surface directly under the wheels was carefully inspected before and after the load test. There was no change or damage. The measured concentrated wheel load on the surface was 15 kips. The backfilling operations and the concentrated wheel load test verify the 2,000 psi criterion as a condition for proceeding with construction after completion of concrete casting.

Instrumentation

The strategy for the study of the performance of the pipe subjected to design loads no less than H20-44, included the following four systems of observation.

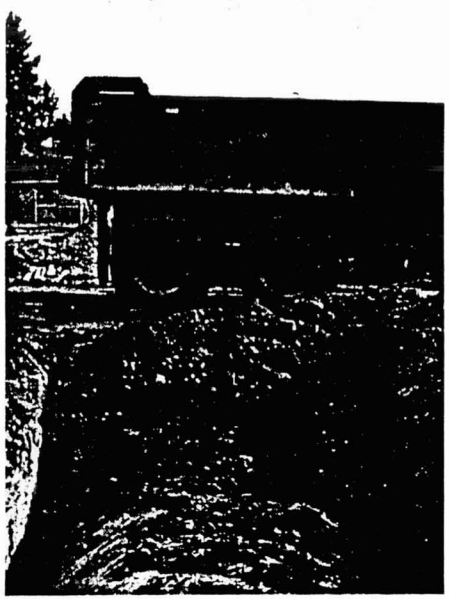


FIG. 3. Loaded Gravel Truck for 72-Hour Test

Visual Inspection

Visual inspection of the interior of the pipe, for evidence of tension cracks, was performed after the placement and removal of the test loads. On the assumption that, in regions of maximum tension (on the interior wall of the pipe, these occur at crown and invert), cracks may form under live load and then close with the withdrawal of the live load from the pipe, a special effort was made to discover evidence of such cracking. To this end these areas were first wet down and then surface-dried. Any tension cracks that may have closed with the withdrawal of load would be expected to show evidence of such cracking due to the capillary draw of water into the crack. The wetting fluid was water-treated with a mild detergent (Fotoflo 200) for the purposes of breaking the surface tension, thereby enhancing the opportunity for the wetting fluid to be drawn into the crack, should cracks be present.

Interface Pressure

Five pressure sensors were positioned in a plane normal to the longitudinal axis of the pipe. Two of these sensors, at 5 and 7 o'clock positions, were placed at the soil-pipe interface soon after the excavation of the trench (October 22) and prior to the placement of the concrete (October 23). The remaining three pressure sensors, at 3, 9, and 12 o'clock positions, were installed on October 27 in the soil in preformed pockets.

Tangential Strains—Inner Pipe Wall

At 24 points around the inner pipe wall surface at approximately every 15° measured clockwise from the crown, a circumferential strain gage was glued to the pipe wall (see Fig. 4). Each gage was calibrated to read directly in microin. of strain. A harness of connecting wires lead to a multichannel switching and balancing unit and digital recording readout instrument, external to the pipe.

loc.	X-cord	Y-cord
1	9.21	35.75
2	17.34	32.48
3	25.65	25.78
4	30.75	18.51
5	34.73	8.73
6	35.74	0.15
7	34.78	-9.16
8	30.55	-18.83
9	25.72	-25.56
10	19.17	-30.82
11	8.91	-35.20
12	0.39	-36.64
13	-8.30	-35.54
14	-17.67	-31.82
15	-25.07	-26.29
16	-31.13	-18.84
17	-35.25	-10.04
18	-36.41	-0.63
19	-35.78	7.14
20	-31.48	19.11
21	-26.84	25.38
22	-19.83	31.40
23	-10.57	35.39
24	0.00	36.50

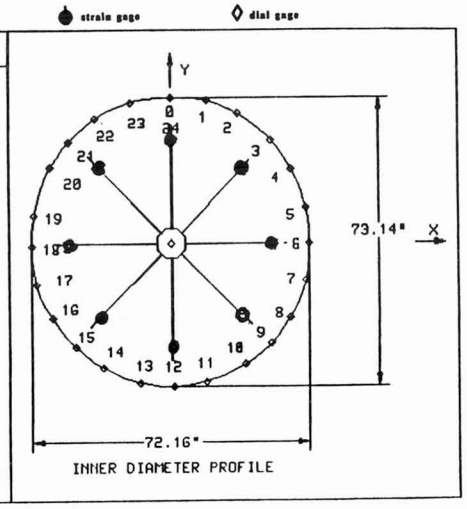


FIG. 4. Location of Strain Gages and Dial Gages

Radial Displacements—Inner Pipe Wall

At eight points around the inner pipe wall surface, at approximately every 45° measured clockwise from the crown, a mechanical spring-loaded dial gage (see Fig. 4), with a least count of 0.0001 in., was positioned to sense the radial displacement of the inner wall of the pipe. The planes of the dial gages and strain gages were sufficiently close (less than 3 in. apart) to be considered coincident. This coincident plane will, in the future, be referred to as the plane of instrument.

The dial gages were each mounted at the end of one of eight spokes radiating from a central hub. The hub was positioned at the center of the inner-wall circle and was supported by a truss-like frame with a base of approximately 22 ft [see Figs. 5(*a*) and 5(*b*)]. Smooth tungsten carbide steel tabs were positioned and glued on the inner wall of the pipe so as to receive the sensing probe of the gage. Enough adjustment potential was built into the system of base, truss, hub, spokes, and gage so as to permit the noted and desired alignment. During the source of the test, the gages were read using a surveyor's transit telescope positioned outside the pipe.

The Test

Intermittent wet weather and wet soils in the test area prevented sufficient time to set up the actual instrumented testing until June of the next year.

On June 22, 1988, the instrumented pipe was live-load tested with an off-highway Euclid RX 35 loaded with aggregate base material to that point where the front axle registered 32 kips (a more critical single-wheel loading than the standard H20-44 dual-wheel loading). The rear-axle loading registered more than twice the standard H20-44 with a maximum dual-wheel load of 35.5 kips.

The latter is the maximum load that was placed directly over the pipe (see Fig. 6). Wheel loads were measured at the site by the California Highway Patrol using standard portable scales.

Live-load testing was started at 1:30 P.M. Three load positions were employed.

1. Front wheels on pipe centerline with right front wheel directly over the instrumented X-section.
2. Front wheels on pipe centerline and centered over the instrumented X-section.
3. Rear right dual wheels on pipe centerline and centered over the instrumented X-section.

Monitoring the instrument readout during loadings clearly showed that load position 1 produced a greater stress than position 2. As previously planned, this same position was used with the heavier rear wheels as the critical test load. The truck was run back and forth several times, then parked in position 3 for approximately 30 minutes while readings and observations were made.

Visual observations and gage readings indicated no distress whatever in the pipe. Since the structure has passed proof load testing (more than twice an H20-44 wheel load, less than 2 ft of cover, unpaved road) no further tests were made.

Following testing, soil borings were taken alongside the pipe to obtain data on the in situ material outside the trench. The materials were consistent

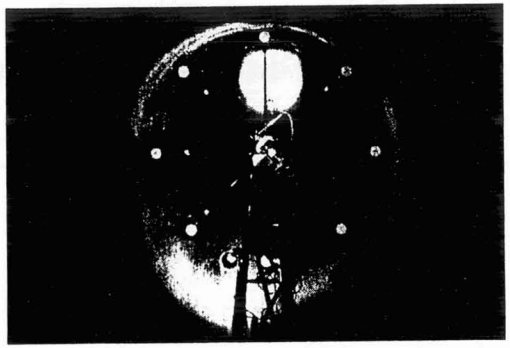


FIG. 5(*a*). Dail Gages and Support Frame

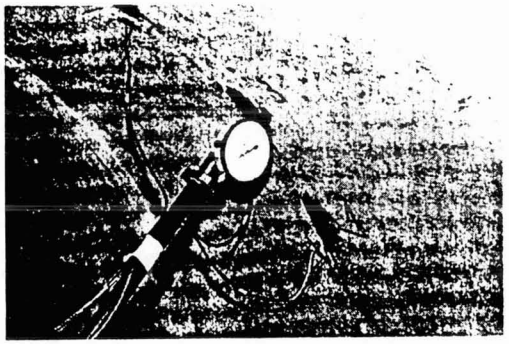


FIG. 5(*b*). Detail of Dial Gages and Strain Gages

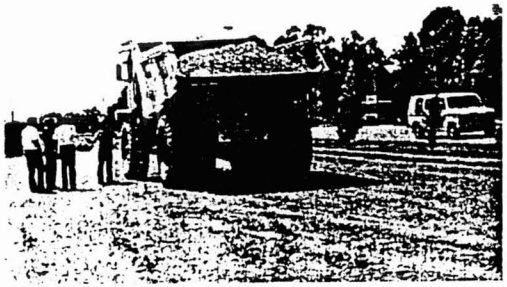


FIG. 6. Loaded Off Road Vehicle for Strength Test

with the initial soil sampling in the trench area, namely clayey silt over silty clay. In-place soil densities varied from 99 pcf to 109 pcf with initial tangential modulus values from 800 to 4,200.

Experimental Results

The experimental results of the study offer a very compelling statement as to the capabilities of the test section, as a reasonable representative of CIPCP, to successfully resist the unusually large test wheel load of more than 35,500 lb (more than twice the 16,000 lb maximum wheel load of the H20-44 highway design load). As will be described in more detail, the visual qualitative test results, the quantitative displacement-gage measurements of radial displacement, and the quantitative strain-gage measurements of inner-wall circumferential strain all confirm the successful response of the pipe.

The pressure sensors, however, did not successfully measure the interface pressures at the five points previously noted in the section on instrumentation. It is important in experimental design to introduce redundant systems of measurement in anticipation of failure of any one system—an event that often takes place. In this study, three systems of measurement were introduced. The strain-gage system of measurement correlated with the displacement system of measurement. The pressure system of measurement failed. The sensor at 12 o'clock was the victim of an open circuit. The other four sensors just did not respond to the interface pressures known to be acting. It is believed that the long period between the time of installation of the pressure sensors (late October 1987), and the time of the load test (early June 1988), may have been responsible for the difficulty. Minor soil settlements, in part due to the rains, which included minor flooding, followed by the necessary subsequent surface regrading, are believed to have caused a disturbance to the previously secure contacts between the sensing face of the pressure gage and the material to be sensed at the interface. It is worth noting that the other instrumentation systems of mechanical displacement gages and electrical strain gages were installed only one day prior to the test.

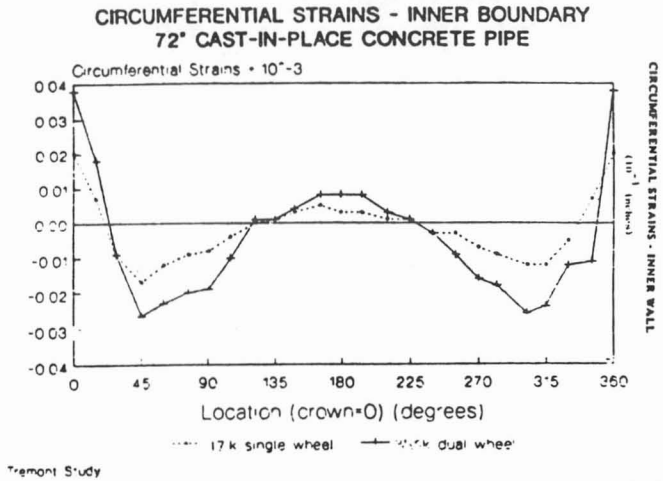
For the following, all measurements of reference are taken at the test section along the inner circumference of the pipe, measured clockwise from the crown as viewed from north to south.

Attention is now drawn to Table 1 and to Fig. 7 wherein circumferential strains are plotted against location. Note the orderliness of the unsmoothed raw strain readings. The largest tension strains occur, as expected, in the vicinities of the crown (0°) and invert (180°). At the haunch, spring line, and some distance below spring line, the expected fields of compression are noted. Also note that the strains from the 35.5-kips wheel load are approximately double those from the 17-kips wheel load. The tensile strains at the crown indicate maximum tensile stress levels in the order of 60–70 psi and 120–140 psi for the 17-kips and 35.5-kips wheel loads, respectively. These stress levels are less than those predicted by the standard industry calculations. The stresses predicted by analysis are 161 psi and 385 psi respectively for the 17-kips and 35.5-kips loads. The difference is a reflection of the conservative nature of the design.

The radial displacements are listed in Table 2 and are plotted versus location on Fig. 8. Note at first, that the displacements are very small, indeed, and that the maximum radial displacement is at the crown and of a magnitude of approximately 0.004 in. inward for the 35.5-kips wheel load,

TABLE 1. Circumferential Strains

Gage Number (1)	Location (degrees) (2)	Strain: 17k on Instrument Line			Strain: 35k on Instrument Line		
		Zero (3)	Load (4)	Strain 10^{-3} (in.) (5)	Zero (6)	Load (7)	Strain 10^{-3} (in.) (8)
24	0.00	−0.004	0.016	0.02	0	0.038	0.038
1	14.57	−0.001	0.006	0.007	−0.002	0.016	0.018
2	28.38	0	−0.009	−0.009	−0.002	−0.011	−0.009
3	45.26	−0.001	−0.018	−0.017	−0.004	−0.03	−0.026
4	60.22	−0.001	−0.013	0.012	−0.002	−0.025	−0.023
5	76.91	−0.001	−0.01	−0.009	−0.003	−0.023	−0.02
6	90.53	−0.001	−0.009	−0.008	−0.003	−0.022	−0.019
7	105.29	0	−0.004	−0.004	−0.002	−0.012	−0.01
8	121.98	0.002	0.002	0	−0.001	0	0.001
9	135.02	−0.002	−0.001	0.001	−0.002	−0.001	0.001
10	148.24	0.001	0.004	0.003	0.002	0.006	0.004
11	165.90	−0.002	0.003	0.005	−0.002	0.006	0.008
12	179.51	−0.003	0	0.003	−0.004	0.004	0.008
13	193.32	−0.001	0.002	0.003	0	0.008	0.008
14	210.20	0	0.001	0.001	−0.002	0.001	0.003
15	224.78	−0.002	−0.001	0.001	−0.005	−0.004	0.001
16	239.93	0	−0.003	−0.003	−0.004	−0.007	−0.003
17	255.27	−0.003	−0.006	−0.003	−0.004	−0.013	−0.009
18	270.23	−0.001	−0.008	−0.007	−0.003	−0.019	−0.016
19	282.49	−0.002	−0.011	−0.009	−0.003	−0.021	−0.018
20	302.67	−0.002	−0.014	−0.012	−0.003	−0.029	−0.026
21	314.94	−0.002	−0.014	−0.012	−0.003	−0.027	−0.024
22	329.51	−0.003	−0.008	−0.005	−0.002	−0.014	−0.012
23	345.43	−0.001	0.006	0.007	−0.004	−0.015	−0.011
24	360.00	−0.004	0.016	0.02	0	−0.038	0.038



Tremont Study

FIG. 7. Plot of Circumferential Strains—Inner Boundary 72-in. CIPCP

and one-half that for the 17.0-kips wheel load. This low level of displacement is compatible wiht the performance of a very stiff soil-pipe response.

A study of the response of the test of the 17.0-kip wheel load (6.5% greater than the standard H20-44) shows the total vertical diameter shortening, rigid-body motion culled out, is approximately 0.0008 in. (0.0022 inward at the crown and 0.0014 outward at the invert). This remarkably low level of deformation response points to the likelihood that it is the whole soil-structure composite that is supporting the active live load. This favorable attribute is judged to be created, in large part, by the intimate contact between the outer pipe wall and the wall of the trench at the interface where the two meet. The passive soil thrusts in the vicinity of the spring line create the counter moments in the pipe wall needed to reduce the tension otherwise created by the wall bending moments.

Attention is drawn to the radial deformation response of the pipe when subjected to the 35.5-kips wheel load (122% greater than the standard H20-44) (see Fig. 8). Note that between crown and spring line (0°–90° and 270–360°) the patterns of radial deformation (solid lines) are such that the recorded displacements of the 17.0-kips and 35.5-kips concentrated loads track one another. Between spring line and invert, the pattern for the 35.5-kips load abruptly changes; the invert moves inward rather than outward. This pattern may be explained by a change in curvature of the pipe shell in the vicinity of the invert, with its effects being registered at 135°, 180°, and 225°. The dotted line in the figure is simply conjecture as to what radial deformations might have occurred in the absence of such a phenomenon.

Very careful and repeated visual inspection of crown and invert revealed no tension cracks. Also, note the low order to the magnitude of the numbers; a measured 0.0015 in. inward at the invert as contrasted with the conjectured 0.0040 in. outward at the invert.

Two possible explanations for this change in curvature are offered:

1. A plastic hinge, at invert, was in the proces of forming. Had a fully formed plastic hinge resulted, it is reasonable to expect tension cracks at the invert, an

TABLE 2. Radial Displacements

Gage Number (1)	Location (degrees) (2)	Deflection: 17k on Instrument Line			Deflections: 35k on Instrument Line		
		Zero (3)	Load (4)	DISPL (in.) (5)	Zero (6)	Load (7)	DISPL (in.) (8)
24	0	0.2019	0.2041	−0.0022	0.2031	0.2068	−0.0037
3	45	0.2017	0.2019	−0.0002	0.2031	0.2028	0.0003
6	90	0.2013	0.2008	0.0005	0.2022	0.2003	0.0019
9	135	0.2192	0.2185	0.0007	0.219	0.2196	−0.0006
12	180	0.2188	0.2174	0.0014	0.2175	0.2189	−0.0014
15	225	0.2181	0.2171	0.001	0.2168	0.2164	0.0004
18	270	0.2188	0.2178	0.001	0.218	0.2152	0.0028
21	315	0.2007	0.2019	−0.0012	0.2012	0.201	0.0002
24	360	0.2019	0.2041	−0.0022	0.2031	0.2068	−0.0037

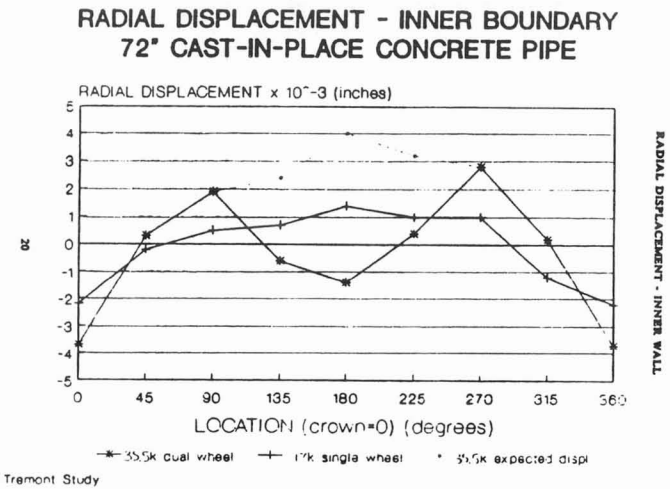


FIG. 8. Plot of Radial Displacement—Inner Boundary 72-in. CIPCP

event that did not take place. The cross-section of the CIPCP, a highly redundant structural element, has a great deal of reserve capacity beyond the formation of a fully developed plastic hinge at invert. Two hinges, say at invert and crown, transform the cross section into two stable two-hinged arches. Two more hinges, say in the vicinity of the spring line on each side of the pipe, transform the cross section into two stable three-hinged arches. The conclusion drawn is that a significant reserve capacity exists in this test pipe even after the application of the 35-kip concentrated dual-wheel load.

2. At some level of load, a threshold is crossed beyond which increasing interface shear in the vicinity of spring line exceeds the capacity of the interacting walls of concrete and soil trench. At this point, some vertical interface slippage occurs, which is resisted more competently at invert than at any point between spring line and invert. This phenomenon would result in a reversal of curvature, the event still wholly contained within the elastic response of the structure (as evidenced by the very small movement and the absence of cracks).

In either case, the conclusion drawn is that the pipe has significant reserve capacity after the application of the 35.5-kips concentrated dual-wheel load.

Analytical Predictions

It is the purpose of this section to illustrate that the performance of CIPCP may be anticipated by calculation. The calculations that follow are standard moment and thrust calculations utilizing Paris ring coefficients (Paris 1921).

The principle of the analysis is to calculate the maximum bending moment and normal thrust force in the pipe wall, and then to algebraically add the bending tension stress to the thrust compression stress. This yields the largest magnitude of tension in the pipe wall, a value that is compared with the modulus of rupture for the concrete (appropriate for nonreinforced concrete where bending dominates the stress field). A factor of safety against failure is calculated.

The loads on the pipe are conservatively taken as line loads, the vertical

live and dead loads at the crown and the horizontal load acting at spring line. Other loads considered are the dead weight of the pipe and the water load within the pipe. This latter is included for discussion, but it does not represent the case of the field test of this report. Design values of concrete strength and geometry are used.

Loads

The live load on the pipe was delivered by a Euclid R35 off-road hauler. The tire size for this hauler is 1800-33, 18 in. wide with rated pressure of 65 psi.

The front axle of the hauler has two wheels; the rear axle has two sets of duals, each wheel of each dual being 5.25 in. clear distance from its companion wheel. The front wheel placed over the test section carried a load of 17.0 kips; the rear dual placed over the test section carried a two-wheel load of 35.5 kips. The wheels of each test section were oriented normal to the longitudinal axis of the pipe.

Front-Wheel Analysis

Vertical Loads

It is common practice to assume that a surface wheel will, for a short length of pipe, load the pipe with a uniform line load acting at the crown. The loading cone shown in Fig. 9 may reasonably lie within those values calculated for $30° < a < 45°$.

An impact factor of 20% increases the 17.0-kips load to 20.4-kips.

Using the conservative estimate $a = 30°$, the live load (LL) is calculated as:

$$LL = \frac{20.4}{1.5 + (2 \times 1.67 \times \tan 30°)} = 5{,}950 \text{ lb/ft} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Using Marston's Theory for earth loading,

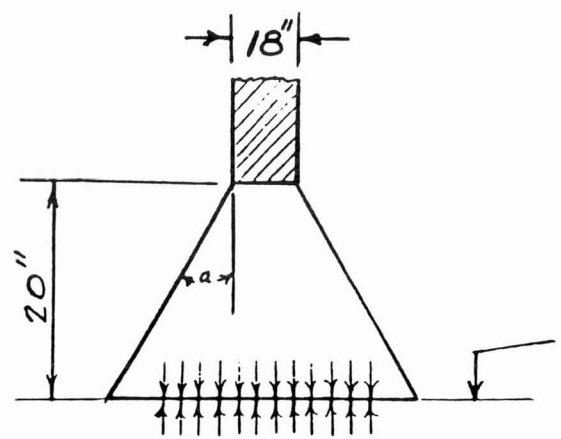


FIG. 9. Diagram of Wheel Load Distribution to 72-in. CIPCP

$$W = C_d w B^2 \quad \text{(2)}$$

where C_d = ditch coefficient = 0.22, for H/B = 1.67/7.25 = 0.23; H = height above crown; and B = trench width.

The trench soil, a slightly moist, firm-to-hard, brown clayey silt has a unit weight of $110 < w < 130$ pcf. Using the large value, the earth load is:

$$W_e = 0.22 \times 130 \times \frac{87}{12^2} = 1{,}500 \text{ lb/ft} \quad \text{(3)}$$

The dead weight of the 72-in. diameter CIPCP W_p = 1,790 lb/ft.

The sum of the live and earth loads (V) is

$$V = \text{LL} + W_e = 5{,}950 + 1{,}500 = 7{,}450 \text{ lb/ft} \quad \text{(4)}$$

Lateral Loads

In the construction of CIPCP, the trench walls and bottom are the forms against which the concrete is cast. Prior to the surface loading of the pipe-soil composite, the self-standing sidewalls neither lean against the pipe (active pressure) nor are they leaned upon by the concrete pipe (passive pressure). When load is placed on the pipe-soil composite (directly above the pipe) on line with the pipe's vertical centerline, the response of the pipe is a slight shortening of the vertical diameter and a correspondingly small lengthening of the horizontal diameter. The effect is to create a lateral passive pressure at the pipe-soil interface of magnitude bounded by the at-rest pressure and full passive pressure. For reasons explained immediately following, the lowest pressure (at rest) is the most conservative and adopted for this study.

Assume that the top portion of the CIPCP works as a structural arch as noted in Fig. 10. The vertical load at the crown represents the sum of the live and earth loads. The lateral thrust, a consequence of active earth pressure (Rankine coefficient >1), is applied at spring line. From equilibrium, it is noted that the vertical reactions ($W/2$) are independent of the lateral thrust (H) and bending moment (M), given symmetry of loads and reactions. Whatever moment H and M excite at other points (say about the crown), is reduced by a moment of opposite sense excited by the spring-line thrusts. For an arch of the geometry noted in Fig. 10, the greater the value of H, the lesser the net moment, illustrating the structural efficiency of the arch.

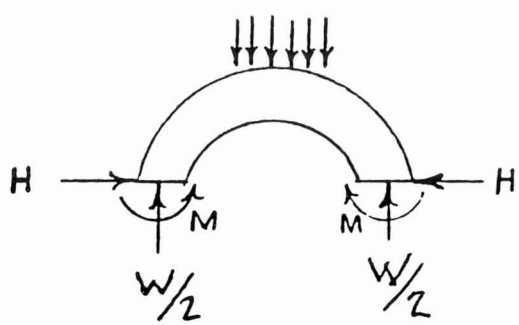


FIG. 10. Plot of Forces Acting on Top Half of 72-in. CIPCP

These same arguments apply for calculation of net moment at invert. Consistent with this, a conservative estimate of the Rankine coefficient of lateral pressure is taken equal to 1 for the purposes of this calculation. Usually a Rankine coefficient of active pressure (0.33) is used in determining the lateral forces at spring line. This is judged to be overly conservative in this prediction calculation in that it is not possible to have active pressure operating against the sidewall of the CIPCP, but undoubtedly reassuring to users.

Analysis for Stresses

The maximum thrust and moment of the pipe section are separately calculated and subsequently added. The conditions of loading follow.

1. Vertical line loads at crown.
   a. Live load.
   b. Earth load above crown.

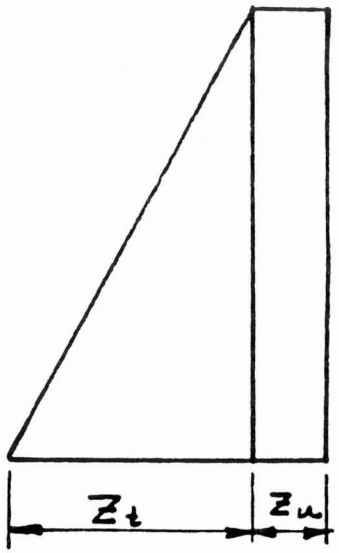
$$\text{Thrust } (T_v) = 0 \quad \text{(5)}$$

due to symmetry of loads and geometry.

$$\text{Moment } (M_v) = 0.125VR = 0.125(7{,}450 \text{ lb/ft})(3.29 \text{ ft})$$

$$= 3{,}060 \text{ ft-lb/ft} \quad \text{(6)}$$

2. Lateral line loads at spring line (see Fig. 11), where T_{lu} = thrust in the pipe wall due to Z_u (lbs/ft of pipe length); M_{lu} = moment in the pipe wall due



Lateral Soil Pressure Diagram

FIG. 11. Lateral Soil Pressure Diagram

to Z_u (ft-lbs/ft of pipe length); T_{lt} = thrust in the pipe wall due to Z_t (lbs/ft of pipe length); M_{lt} = moment in the pipe wall due to Z_t (ft-lbs/ft of pipe length); and R = radius to center of pipe wall (ft).

a. Rectangular pressure distribution.

Thrust $(T_{lu}) = 1.0(Z_u)(R) = 1.0(kw'H)R = 1.0(1 \times 110 \times 1.67)(3.29)$

$= 550$ lb/ft min $= 1.0\ (1 \times 130 \times 1.67)(3.29) = 710$ lb/ft max ..... (7)

Moment $(M_{lt}) = -0.250(Z_u)R\hat{}2 = -0.250(1 \times 130 \times 1.67)$

$\times (3.29)\hat{}2 = -590$ ft-lb/ft ..... (8)

b. Triangular pressure distribution.

Thrust $(T_{lt}) = 1.375(Z_t)R\hat{}2 = 1.375(kw')R\hat{}2 = 1.375(1 \times 110)(3.29)\hat{}2$

$= 1{,}640$ lb/ft min $= 1.375(1 \times 130)(3.29)\hat{}2 = 1{,}930$ lb/ft max ..... (9)

Moment $(M_{lt}) = -0.292(Z_t)R\hat{}3 = -0.292(1 \times 130)(3.29)\hat{}3$

$= -1{,}350$ ft-lb/ft ..... (10)

3. Dead weight of pipe.

Thrust $(T_p) = 0.027(W_p) = 0.027(1{,}790) = 550$ lb/ft ..... (11)

Moment $(M_p) = 0.070(W_p)\mathrm{R} = 0.070(1{,}790)3.29 = 710$ ft-lb/ft .... (12)

Totals (exclusive of water in the pipe):

$T(\min)$ = Thrust(min soil wt) $= 0 + 550 + 1{,}640 + 50$

$= 2{,}240$ lb/ft ..... (13)

$T(\max)$ = Thrust(max soil wt) $= 0 + 710 + 1{,}930 + 50$

$= 2{,}690$ lb/ft ..... (14)

M = Moment $= 3{,}060 - 590 - 1{,}350 + 410 = 1{,}530$ ft-lb/ft ..... (15)

Maximum stress:

$$f = \frac{-T(\min)}{12t} + \frac{617}{t\hat{}2} \quad \text{..... (16)}$$

$$f = \frac{2240}{-12 \times 7} + \frac{6 \times 1530}{(7)\hat{}2} = 161 \text{ psi} \quad \text{..... (17)}$$

With a modulus of rupture for $fc' = 3{,}000$ psi concrete taken at 492 psi, the factor of safety = 3.0. The 17.0-kip wheel load is predicted to cause no distress to the CIPCP, nor did it. Modulus of rupture is taken as 9.0 $\sqrt{fc'}$ (*ACI Materials Journal*, 1990).

Rear-Wheel Analysis

In Fig. 12, note that each of the 18-in. dual wheels, spaced 5.4 in. apart, will distribute the live load a distance of 41 in. along the crown of the pipe, when the angle with the vertical is 30°. For a 35.5-kip dual-wheel load, the effective crown-line load, $(2 \times 17.75 \times 12 \times 1{,}000)/41 = 10{,}390$, which

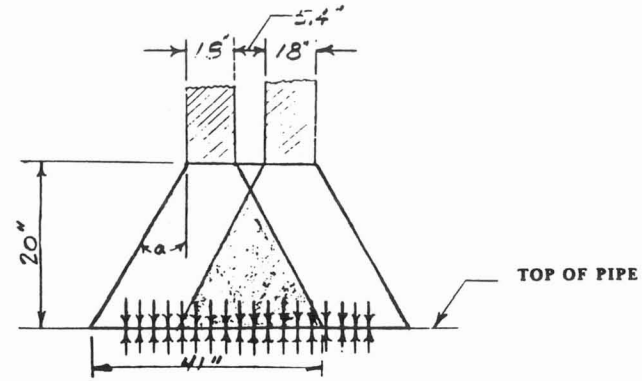


FIG. 12. Diagram of Rear Wheel Load Distribution for Field Test of 72-In. Diameter CIPCP

is greater than $1.20 \times 35{,}500/5.37 = 7{,}930$ lb/ft. The total vertical load is (V):

$V = \mathrm{LL} + W = 10{,}390 = 1{,}500 = 11{,}890$ lb/ft ..... (18)

The moment for this heavier load is

$M = 0.125VR = 0.125(11{,}890)3.29 = 4890$ ft-lb/ft ..... (19)

Including the same (as for the earlier calculation of front-wheel load) effects of lateral forces and weight of pipe, the maximum moment $= 4{,}890 - 590 - 1{,}350 + 410 = 3{,}360$ ft-lb/ft, resulting in a maximum tensile stress of:

$$\frac{-T}{12t} + \frac{6M}{t\hat{}2} = \frac{-2{,}240}{12 \times 7} + \frac{6 \times 3{,}360}{7\hat{}2} = 385 \text{ psi} \quad \text{..... (20)}$$

for a factor of safety based on rupture modulus = 1.2. Distress is not predicted for the CIPCP with a dual-wheel load of 35.5 kips, nor did it occur.

Pipe Filled with Water

As a comment, although the test pipe was not filled with water, it is interesting to note that, had the pipe been carrying a full load of water (exclusive of head), it still is predicted to perform well. The thrust and moment:

Thrust $(T) = -0.451W = -0.451(1{,}765) = -800$ lb/ft ..... (21)

Moment $(Mw) = 0.070R = 0.070(1{,}765)3.29 - -410$ ft-lb/ft ..... (22)

For the case of the dual rear wheels, the maximum tensile stress is:

$$\frac{-2{,}240 - 800}{2 \times 7} + 6 \times \frac{3{,}360 + 410}{7\hat{}2} = 445 \text{ psi} \quad \text{..... (23)}$$

The safety factor based on rupture modulus is 1.1.

Prediction Using fc' Actual

The design calculations used for prediction are based on $fc' = 3{,}000$ psi, the 28-day design strength of the concrete specified. In actuality, the design strength of the concrete 7 months after the 28-day breaks was determined to be 4,800 psi by the CALTRANS testing laboratory. Based upon this strength, the modulus of rupture is 624 psi. Safety factors for the 17-kip and 35.5-kip loads are 3.2 and 1.5, respectively.

Conclusions

1. The 72-in. diameter cast-in-place nonreinforced concrete pipe (CIPCP) constructed to the standard dimensions and material specifications for the product can be safely used under H20-44 highway loads with as little as 2 ft of cover, with or without pavement.
2. Normal backfilling of the pipe may be started when the minimum compressive stress of the concrete reaches 2,000 psi.
3. Performance of this product is dependent upon competent structural support from the in situ soil, which is assured by the construction-site requirements for the product. The properties of the soil at the test section met the established specifications of vertical free-standing trench walls through pipe zone and uniform, firm invert trench, for the in situ material. These practical standards for acceptable sidewall soil have been established by some 35 years of experience, and are described in specifications by American Concrete Institute and many state and local-agency standard specifications. The results verify the suitability of these standards for a normal H20-44 loading.

Acknowledgments

The authors wish to thank principals at CALTRANS; notably, James E. Roberts, Chief Officer of Structural Design; A. E. Bacher, Underground Structures Engineer (retired); Craig Chatelain, Underground Structures Engineer; K. A. Jackura, Office of Transportation Laboratory. We also want to thank L. G. "Muggs" Schroeder, who directed the pipe installation for Tremont Equipment Co.; Teichert Aggregates, Sacramento, who supplied the concrete; Granite Construction Co., Sacramento, who supplied the test vehicles; Wallace & Kuhl Geotechnical Engineering, West Sacramento, who did the concrete sampling and testing; Fred Carpenter, State Traffic Officer Commercial Enforcement, California Highway Patrol, who weighed and certified the wheel weights; and finally James Ster III and Brett Anthony of the Technical Shop of the School of Engineering and Computer Sciences at California State University, Sacramento, who built the instrumentation systems.

Appendix I. Conversion to SI Units

To convert	To	Multiply by
in.	mm	25.4
ft.	m	0.3048
cu ft.	m^3	.0283
lb	kg	0.4536
lb force/ft	N/m	14.59
psi	MPa	0.00689
kips	kg	453.6

Appendix II. References

"American Concrete Institute 346-90 Specifications & 346R-90 Recommendations for cast-in-place nonreinforced concrete pipe." (N/A). *Manual of concrete practice*, American Concrete Inst., Detroit, MI.

Paris, J. M. (1921). "Stress coefficients in large horizontal pipes." *Engineering News Record*, 8(19), 768–770.

Soil engineering. (N/A). Spangler and Handy Intext Educational Publishers.

TRANSPORTATION RESEARCH

RECORD

No. 1415

Soils, Geology, and Foundations

Field Performance of Structures and Nondestructive Evaluation of Subsurface Infrastructure

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1993

Field Performance of Cast-in-Place Nonreinforced Concrete Pipe

CURTISS W. GILLEY AND L. H. GABRIEL

A compilation of case histories of cast-in-place nonreinforced concrete pipe (a continuous monolithic cast underground conduit for irrigation water, storm water, sewage, and industrial waste) is presented. The results of field tests corroborate the value of passive restraint at the springline. Eight field studies dating back to 1954 demonstrate the load-carrying and hydrostatic capabilities of cast-in-place concrete pipe.

The case studies of nonreinforced cast-in-place concrete pipe (CIPCP) presented encompass a period of more than 38 years of in-service field experience.

By American Concrete Institute (ACI) Specification 346 definition, "CIPCP is an underground continuous nonreinforced concrete conduit, having no joints or seams, except as necessitated by construction requirements. It is intended for use to convey irrigation water, storm water, sewage, or industrial waste under a maximum internal operating head of 45 kPa (15 ft.) and external loads . . ." (*1*).

HISTORY OF CIPCP

Although a process for cast-in-place concrete pipe was first patented in 1897, it was not until the early 1920s that the Turlock Irrigation District in California's San Joaquin Valley pioneered its commercial use. Unlike today's machine monolithic casting process, these early pipes were hand (and later, machine) cast in two semicircular segments. Undesirable cold joints appeared at springline where the two segments joined.

The first modern casting machines was used in 1949. Because the function of these pipes in that year was for irrigation water, sizes were limited to 1220 mm (48 in.) in diameter. Application to storm sewer pipelines quickly followed in the early 1950s. Today, sizes with diameters of 610 mm (24 in.) through 3048 mm (120 in.) are routinely constructed. Approximately 3500 km (2,200 mi) of CIPCP has been installed to date, with approximately 22 percent with diameters of 1372 mm (54 in.) or larger. Most of the installations are located in California, Arizona, Texas, New Mexico, Oregon, and Washington. CIPCP has also been installed in Mexico City, Mexico, and Johannesburg, South Africa.

STRUCTURAL PERFORMANCE OF CONCRETE PIPE

The dominating characteristic of a brittle material, such as concrete, is a low threshold of tensile capability. For the reliable performance of concrete pipe, either the internal tensile forces must be transferred, through bond, to tough, ductile, steel reinforcing bars of large tensile capacity or the internal tensile forces must be significantly reduced by developing a compensating force field. Precast reinforced concrete pipe (RCP) is an example of the former; nonreinforced CIPCP is an example of the latter.

When responding to the application of loads, the pipe wall internal reacting forces of shear, in-plane thrust (wall thrust), and bending moment (wall bending) all contribute to the composite stress response. For rigid structures, such as concrete pipe, secondary stress effects due to deflections are assumed negligible; the deformed structure lies well within the bounds of small deflection theory.

The in-plane circumferential stress of wall thrust may be added arithmetically to the flexural stress of wall bending because both forces result in parallel stress fields that track the wall circumference. A properly designed and constructed CIPCP will enjoy an increase in the favorable wall thrust and a decrease in the unfavorable wall bending so as to mask, or nearly mask, the wall-bending tensile stress to which concrete is vulnerable. This is accomplished by the self-induction of passive lateral forces in the vicinity of springline when the lengthening horizontal diameter (under increasing load) engages the stiff walls of the trench which previously served as forms for the casting of the pipe. This is not unlike the way an arch structure develops lateral reaction forces at the supports, which serves to increase internal thrust and decrease internal bending. RCP, which does not enjoy the full benefits of the compensating effects of lateral support at springline, utilizes reinforcement to engage the high tensile stresses that result from wall bending.

CONSTRUCTION PROCEDURES

The first step in the construction process is to excavate a trench with vertical side walls and a round bottom, shaped with a round bottom bucket attached to a tracked excavator or backhoe. [For further information, see the Lynch Manual (*2*) pipe and trench detail, Figure 1, and Table 1.] Alignment is laser controlled.

The pipe casting machine (Figure 2) is placed in the trench, and its motor-driven winch system (Figure 3) is secured to an installed trench anchor. At the start of the process, and continuing in pace with the advancing casting machine, loose metal top forms shaping and containing the upper 270 degrees are positioned to receive concrete. Through a hopper that is integral with the casting machine, a low-slump 25- to 76-mm

C. W. Gilley, Tremont Equipment Co., Inc., 6940 Tremont Road, Dixon, Calif. 95620-9603. L. H. Gabriel, School of Engineering, California State University, 6000 J Street, Sacramento, Calif. 98519-2694.

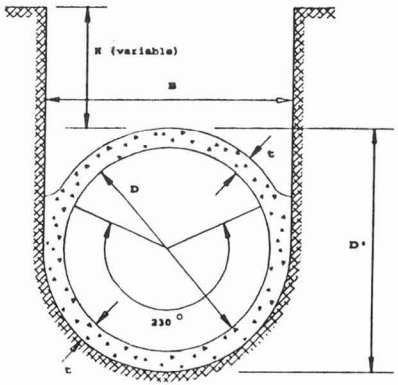


FIGURE 1 Typical cross section of cast-in-place concrete pipe [610–3048 mm (24–120 in.)].

(1- to 3-in.) concrete of modest strength with a minimum 28-day strength of 20.7 MPa (3,000 psi) is placed, tamped, and vibrated to achieve full consolidation. A polyethylene blanket is often used for accelerated curing. Under typical conditions, the production rate ranges from 30 m (100 ft) to 7 m (23 ft) per hour depending on the size, 610-mm diameter to 3048-mm diameter, of the pipe.

After 6 hr, the top forms may be removed. When the concrete achieves a strength of 17.2 MPa (2,500 psi), usually in 2 to 3 days, trench backfilling may begin. Circumferential shrinkage cracks, which are best understood to be joints in the continuously cast pipe, will appear every 7.6 m (25 ft) to 15.2 m (50 ft), or more, depending on curing conditions, the quality of the concrete, and trench moisture conditions. The cracks have no structural significance and need only to be grouted to prevent infiltration, if such is a consideration.

DESIGN CONSIDERATIONS

The following ACI (*1*) engineering design procedure yields a statement of the stress in the pipe wall.

Marston earth loads for the trench conditions are used to define vertical dead loads. Appropriate AASHTO highway loads, FAA aircraft loads, and Cooper rail loads define the live loads. Compensating lateral loads (see section on Structural Performance of Concrete Pipe) are taken conservatively as Rankine active pressures, a significant underestimate of the passive pressures known to be working when the stiff lateral walls are engaged by the pipe. The pipe dead load, the weight of the water in the pipe, and hydrostatic heads may be included as required.

Moments and thrusts may be computed using coefficients developed by Paris (*3*) or Roark compiled by Young (*4*). Stresses at critical points of tension (at crown, invert, and springline) are calculated in appropriate units from the following interaction formula:

$$f = (6M/t^2) - (T/t)$$

TABLE 1 Dimensions of Cast-in-Place Concrete Pipe

NOMINAL DIAMETER (Interior)		OUTSIDE DIAMETER (Depth)		WIDTH OF PIPE/TRENCH (Nominal)		WALL THICKNESS (Minimum)	
D		D'		B		t	
mm	inches	mm	inches	mm	inches	mm	inches
610	24	762	30	787	31	76	3.0
686	27	838	33	864	34	76	3.0
762	30	914	36	940	37	76	3.0
914	36	1092	43	1118	44	89	3.5
1067	42	1270	50	1295	51	102	4.0
1219	48	1473	58	1499	59	127	5.0
1372	54	1651	65	1676	66	140	5.5
1524	60	1829	72	1854	73	152	6.0
1676	66	2007	79	2032	80	165	6.5
1829	72	2184	86	2210	87	178	7.0
1981	78	2362	93	2388	94	191	7.5
2134	84	2540	100	2565	101	203	8.0
2438	96	2896	114	2921	115	229	9.0
2743	108	3277	129	3302	130	267	10.5
3048	120	3658	144	3683	145	305	12.0

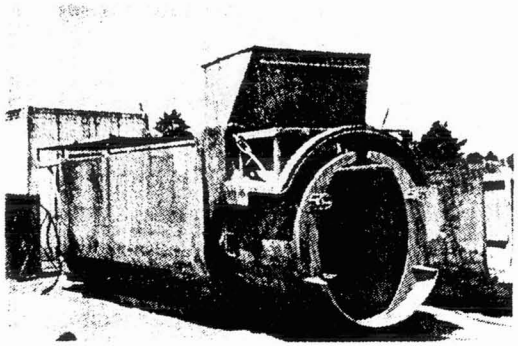


FIGURE 2 Pipe casting machine.

where

M = moment per unit length of pipe (N·m/m),
t = thickness (mm),
T = circumferential thrust per unit length of pipe (m), and
f = stress (MPa).

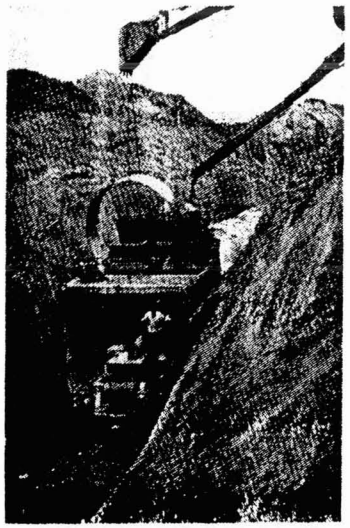


FIGURE 3 Pipe case in prepared trench.

Alternatively, a stress analysis may be obtained from finite element studies, such as CANDE, wherein a round pipe of constant wall thickness may be used to approximate the configuration shown in Figure 1.

FIELD PERFORMANCE STUDIES

The following is a list of studies known to the authors that illustrate the structural performance of CIPCP.

1. Gravity load test performed by Fortier (*5*), 1954, Fresno, California; pipe diameter = 762 mm (30 in.); soil type, sandy loam/silica with cemented hardpan; f'_c = 15.2 MPa (2,200 psi); loading with modified ASTM sand box; visual observation for distress.

Test and results: A 4-ft section was loaded to 288 kN (43,000 lbf). There was no visible cracking.

2. Hydrostatic load test by Fortier (*5*), 1954, Fresno, California; pipe diameter = 762 mm (30 in.); soil type, sandy loam/silica with cemented hardpan; f'_c = 15.2 MPa (2,200 psi); hydrostatic loadings; instrumented with Type IDP marsh gauge with a pressure range of 0 to 0.69 MPa (0 to 100 psi).

Test and results: A 13-ft test section was bulkheaded and hydrostatically loaded. A pipe rupture occurred at 229 kPa (33.2 psi) or 23.4 m (76.7 ft) of head.

3. Shallow burial test by Johnson and Hess (*6*), 1963, Tucson, Arizona; pipe diameter = 1219 mm (48 in.); in situ soil type, cemented sand and gravel; compacted fill around pipe at 100 percent compaction (ASTM T-180), 228 kg/m³ (143 pcf); cover, 0.15 m (0.5 feet); f'_c = 27.5 MPa (4,000 psi); truck axle and wheel loads; instrumented with strain gauges, dial gauges, and Carlson pressure cells.

Test and results: A maximum wheel load of 125 kN (28,000 lbf) was applied. No distress was observed visually or by instruments.

4. Shallow burial, early live load field test by Gabriel (*7*), 1964, Sacramento, California; pipe diameter = 1830 mm (72 in.); in situ soil type, partially cemented sandy silt; cover, 300

mm (12 in.); 3-day f'_c = 10.3 MPa (1,500 psi); truck axle loads; instrumented with deflection gauges.

Test and results: An axle load of 142 kN (32,000 lbf) was applied after 3 days. No distress was observed visually or by instruments.

5. Field load test by Gabriel (*8*), 1967, Sacramento, California; pipe diameter = 2134 mm (84 in.); in situ soil type, caliche hardpan; f'_c = 20.7 MPa (3,000 psi); early live loads with compaction equipment; instrumented with strain gauges and deflection gauges.

Test and results: Backfilled to 3.7 m (12 ft) and compacted with standard equipment 4 days after pipe was cast. No distress was observed visually or by instruments.

6. Shallow burial load test by Lum (*9*), 1969, Honolulu, Hawaii; pipe diameter = 610 mm (24 in.); in situ soil, stiff red clayey silt; 7-day f'_c = 22.7 MPa (3,292 psi); cover, 0.3 m (1 ft) over CMP, 0.0 to 0.3 m (0 to 1 ft) over concrete pipes; tractor-scraper wheel loads; instrumented with deflection gauges.

Test and results: A 200-kN (45,000-lbf) wheel load was moved over CIPCP, RCP (Class IV), and CMP. No distress was observed in concrete pipes; deflection of RCP was 8 to 10 times that of CIPCP. Large vertical and horizontal deflections of CMP were visually observed.

7. Zero cover static load tests and shallow cover, 0.3 m (1 ft), for dynamic tests by White and Underwood (*10*), Dallas, Texas, 1969; pipe diameter = 2440 mm (96 in.); f'_c = 40.9 MPa (5,920 psi); soil type, clayey sand; sand boxes (static tests) with hydraulic jacks, dynamic loads with falling weights; instrumented with strain and deflection gauges.

Tests and results: Static loads up 912 kN (205,000 lbf) were applied; no cracks were observed visually or by instruments. Dynamic loads up to 65 kN-M (48 ft-kps) were applied; no cracks were observed visually or by instruments.

8. Shallow burial field load test by Gabriel et al. (*11*), 1987–1988, Sacramento, California; pipe diameter = 1830 mm (72 in.); in situ soil type, hard silty clay; f'_c = 27.6 MPa (4,000 psi); cover: 0.5 m (20 in.); compaction equipment loading; instrumented with strain gauges, dial gauges, and pressure cells.

Test and results: Deflections and strains successfully measured the effects of 2+ times H2O loading. Instruments sensed a possible crack; however, none were observed visually.

CONCLUDING REMARKS

The success of CIPCP, as shown in the preceding section, offers evidence that when passive trench wall forces in the vicinity of the springline may be counted upon to develop an archlike response in the pipe to vertical loads, tensile stresses are kept below the cracking threshold. This permits economically efficient use of unreinforced concrete for culverts, pipelines, and other underground structures.

REFERENCES

1. *Recommendations for Cast-in-Place Nonreinforced Concrete Pipe*. ACI 346R-90. American Concrete Institute, Detroit, Mich.
2. *Cast-in-Place Concrete Pipe Process* (Lynch Manual). Tremont Equipment Co., Inc., Dixon, Calif., 1990.
3. Paris, J. M. Stress Coefficients for Large Horizontal Pipes. *Engineering News-Record*, Vol. 87, No. 19, Nov. 10, 1921, pp. 768–771.
4. Young, W. C. *Roark's Formulas for Stress and Strain*, 6th ed. McGraw-Hill Book Co., 1989.
5.* Fortier, E. C. *Tests on 30-inch No-Joint Concrete Pipe*. Unpublished report. Fresno, Calif., June 1954.
6. Johnson, M. A., and J. D. Hess. Load Testing of No-Joint Cast-in-Place Concrete Pipe, In *Highway Research Record 30*, HRB, National Research Council, Washington, D.C., 1963, pp. 20–40.
7.* Gabriel, L. H. *Load Testing of 72-Inch No-Joint Cast-in-Place Concrete Pipe with Shallow Cover*. Unpublished report. Sacramento State College Foundation, Sacramento, Calif., 1964.
8.* Gabriel, L. H. *A Study of Displacements of No-Joint 84-inch Cast-in-Place Pipe Soon After Construction*. Unpublished report. Sacramento State College Foundation, Sacramento, Calif., 1967.
9.* Lum, W. *Report of No-Joint Concrete Pipe Field Test Demonstration—Strength of 24-inch Pipe at Mililani Subdivision*. Unpublished report. Honolulu, Hawaii, Mar. 1969.
10.* White, A., and A. C. Underwood. *Field Sand Box Tests*. Unpublished report. Underwood and Associates, Houston, Tex., 1969.
11.* Gilley, C., L. Gabriel, and R. Standley. Field Test of 72 in.-Diameter Cast-in-Place Nonreinforced Concrete Pipe. Paper No. 26533. *Journal of Transportation Engineering*, ASCE, Vol. 118, No. 1, Jan./Feb. 1992.

**Copies of unpublished reports are available from Tremont Equipment Co., 6940 Tremont Road, Dixon, Calif. 95620-9603.*

Publication of this paper sponsored by Committee on Subsurface Soil-Structure Interaction.