Report No. KS-22-01 ▪ FINAL REPORT ▪ April 2022

Evaluation of High Density Polyethylene (HDPE) Pipes K-66 Cherokee County

David A. Meggers, P.E.
Kansas Department of Transportation
Bureau of Research
(Retired)

Kansas Department of Transportation

1 Report No. KS-22-01	2 Government Accession No.	3 Recipient Catalog No.
4 Title and Subtitle Evaluation of High Density Polyethylene (HDPE) Pipes K-66 Cherokee County		5 Report Date April 2022
		6 Performing Organization Code
7 Author(s) David A. Meggers, P.E.		8 Performing Organization Report No.
9 Performing Organization Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		10 Work Unit No. (TRAIS)
		11 Contract or Grant No.
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		13 Type of Report and Period Covered Final Report
		14 Sponsoring Agency Code
15 Supplementary Notes For more information write to address in block 9.		

16 Abstract

The purpose of this project was to install several sections of high density polyethylene (HDPE) pipe for initial and long-term evaluation. Three sections of pipe were installed. Two sections of 24-inch diameter and one section of 30-inch diameter pipe were installed during the reconstruction of K-66 between Riverton and Galena, Kansas. The pipes were inspected for damage due to construction and measured for deflections shortly after installation and then intermittently for the next 25 years.

17 Key Words Plastic pipe, Highways, Pipe laying, Deflection, Condition surveys		18 Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service www.ntis.gov.	
19 Security Classification (of this report) Unclassified	20 Security Classification (of this page) Unclassified	21 No. of pages 48	22 Price

Form DOT F 1700.7 (8-72)

This page intentionally left blank.

Evaluation of High Density Polyethylene (HDPE) Pipes K-66 Cherokee County

Final Report

Prepared by

David A. Meggers, P.E.

Kansas Department of Transportation
Bureau of Research

A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

April 2022

© Copyright 2022, **Kansas Department of Transportation**

NOTICE

The authors and the state of Kansas do not endorse products or manufacturers. Trade and manufacturers names appear herein solely because they are considered essential to the object of this report.

This information is available in alternative accessible formats. To obtain an alternative format, contact the Office of Public Affairs, Kansas Department of Transportation, 700 SW Harrison, 2nd Floor – West Wing, Topeka, Kansas 66603-3745 or phone (785) 296-3585 (Voice) (TDD).

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the state of Kansas. This report does not constitute a standard, specification or regulation.

Abstract

The purpose of this project was to install several sections of high-density polyethylene (HDPE) pipe for initial and long-term evaluation. Three sections of pipe were installed. Two sections of 24-inch diameter and one section of 30-inch diameter pipe were installed during the reconstruction of K-66 between Riverton and Galena, Kansas. The pipes were inspected for damage due to construction and measured for deflections shortly after installation and then intermittently for the next 25 years.

Acknowledgments

Thanks to La Forge and Budd Contractor for the installation of the Polyethylene Pipe sections. Thanks to Advanced Drainage Systems (ADS) Inc. for supplying the pipe, technical assistance during the installation and a construction field report, Appendix B. Thanks to Robert Gudgen and Jack Amershack of the Pittsburg, Kansas Department of Transportation (KDOT) Construction office. Thanks to the KDOT Bureau of Research personnel who have assisted over the years to collect the data necessary to evaluate the pipe structures.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction and Project Description

During the summer of 1995, the Kansas Department of Transportation (KDOT) performed a rebuild of Highway K-66 between Riverton and Galena, Kansas. During the construction, performed by LaForge and Budd Construction, three sections of high-density polyethylene (HDPE) pipe, supplied by Advanced Drainage Systems (ADS) Inc., were installed. Two of the pipes were 24 inches in diameter (Station 283+35 and 361+25) while the third pipe was 30 inches in diameter (Station 332+57). The asphalt pavement structure consisted of 10 inches of AB-4 Sub-Base, 7 inches of HR-2C or BM-2C Base Course, and 1 inch of BM-1T Surface Course. Minimum cover requirements were met or exceeded on each installation. The objective of this project was to evaluate polyethylene (PE) pipes for future use by the KDOT for mainline drainage crossings. Areas of concern were the stiffness during construction and resistance to damage due to construction traffic and the long-term durability of the pipes.

The KDOT determined pipe deflections and inspected for cracks shortly after completion of construction and intermittently over the following 25 years. Pipe deflections and damage were checked in 2003 and 2012. A visual evaluation was performed in 2021.

The research for this project followed AASHTO specifications as KDOT had not yet developed specifications for polyethylene pipe. Use by other state DOTs as well as private contractors of PE pipes and the results of their projects were taken into consideration. The use of PE pipes as a faster installation and lower cost alternative to concrete, steel, and aluminum pipes was evaluated. PE pipes are anti-corrosive, which concrete, steel, and aluminum pipes are not. The PE pipes are more resistive to some of the acidic and alkaline runoff that Kansas has from mining, agricultural fields, and feedlots, and have a life expectancy of 50 years.

Chapter 2: Project Results

Shortly after the west 24-inch pipe was placed it suffered minor damage and excessive deflection due to construction traffic before sufficient cover was in place. The three pipes were surveyed in 1996 one year after completion of construction. Several stations along each pipe indicated positive deflections. This could be caused by the sides of the pipe being deflected inward slightly while back filling, thus causing an egg shape. Some of the positive deflections were also an indication of the actual diameter of the pipes, 24.1 inches and 30.1 inches for the 24-inch pipes and the 30-inch pipe, respectively. The deflections were calculated using the nominal diameter of the pipes rather than the actual diameter of the pipes as is standard procedure. Diameter measurements below the nominal pipe diameter are shown as negative numbers. See Appendix A, ADS N-12, HP Pipe Specifications.

The 24-inch pipe on the east end of the project indicated a maximum deflection of 4.0 percent at Station 10 in 1996 and at Station 30 during the 2012 reviews (See yellow highlighted cell in Table 1 and Figure 1). This pipe also had what appeared to be a survey error at Station 60 during the 2012 review (See blue highlighted cell in Table 1). This will be discussed later in this report. The data shows several missing stations in the surveys; this was due to the size of the pipe, the slope of the pipe, and the difficulty in making a level turn inside the pipe. All measured deflections were within the accepted established allowable maximum deflection of 5 percent. Survey notes from 2003 indicate two visible circumferential cracks near both ends of the pipe. One was measured to be 15 inches long and the other 10 inches long. 2012 and 2021 indicate significant mower damage of the invert and the end section on the north end of the pipe.

Table 1: 24 Inch Pipe, East End, Station 361+25

Station	Percent Deflection, **1996**	Percent Deflection, **2003**	Percent Deflection, **2012**	Percent Deflection, **Average**
0	1.0	-3.0	-0.5	-0.8
10	-4.0	-1.0	-3.5	-2.8
20	-1.5	-1.5	-1.0	-1.3
30	-2.0	-0.5	-4.0	-2.2
40	-2.0			-2.0
50	-2.5	-3.5		-3.0
60	-1.0	-1.0	5.5	-1.0
70	-3.0	-0.5	-2.5	-2.0
80	-1.5	-3.0	-1.0	-1.8
90	0.5	2.0	0.0	0.8

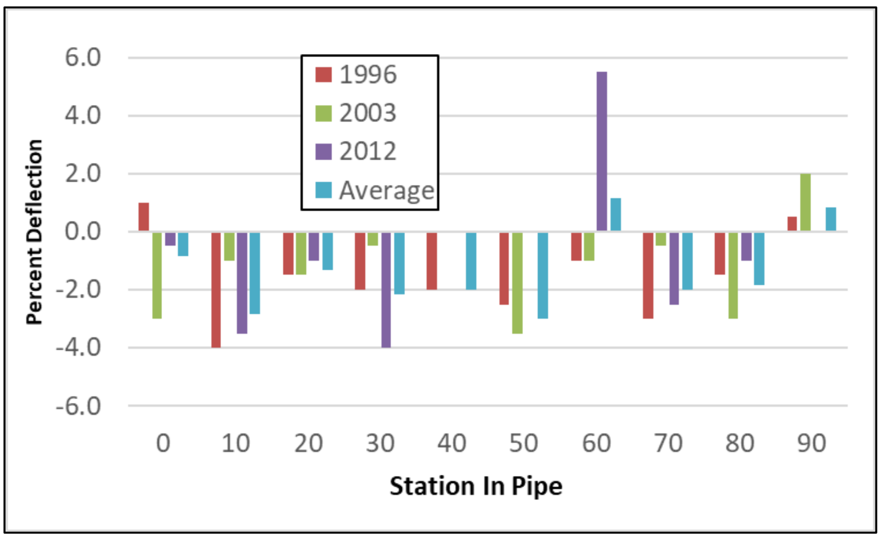


Figure 1: 24 Inch Pipe, East End, Station 361+25

The 30-inch pipe indicated a maximum deflection of 2.4 percent (See yellow highlighted cell in Table 2 and Figure 2). This pipe also appeared to have a significant survey error at Station 70 during the 2003 survey (See blue highlighted cell in Table 2), this will also be discussed later in this report. All other measured deflections were below the acceptable maximum of 5 percent.

The survey notes of 2021 indicated significant damage to the north end section. This damage was most likely due to mowing.

Table 2: 30 Inch Pipe, Middle, Station 352+57

Station	Percent Deflection, **1996**	Percent Deflection, **2003**	Percent Deflection, **2012**	Percent Deflection, **Average**
0	2.4	1.2	2.8	2.1
10	2.4	0.8	2.8	2.0
20	-0.8	0.0	1.2	0.1
30	2.0	2.0	3.2	2.4
40	-2.4	-0.8	1.2	-0.7
50	0.0	1.6	3.2	1.6
60	-2.0	0.0	0.8	-0.4
70	-1.6	4.8	-1.6	-1.6
80	0.0	2.0	1.2	1.1

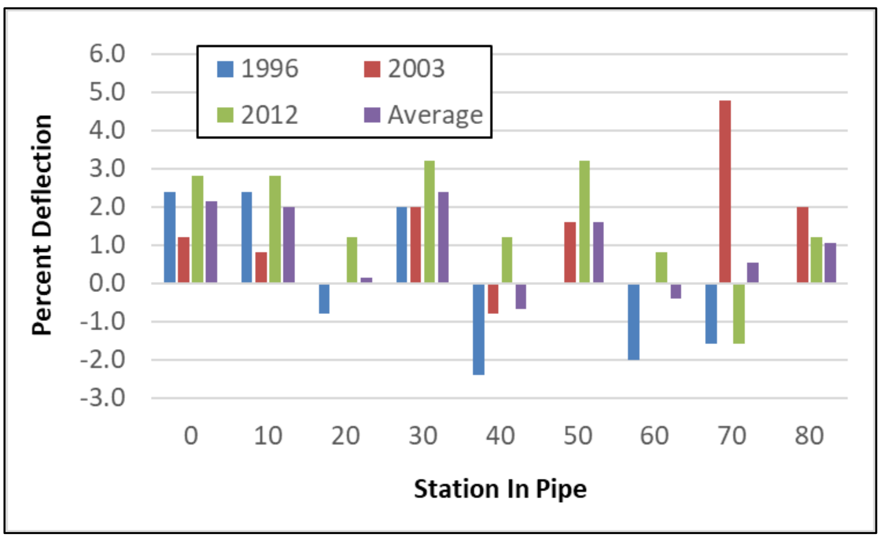


Figure 2: 30 Inch Pipe, Middle, Station 352+57

The west 24-inch pipe indicated a deflection of 10.5 percent when surveyed in 1996 (See yellow highlighted cell in Table 3 and Figure 3). As stated previously this was caused by construction traffic. It was decided to leave this pipe in place to allow for long term evaluation of an installation with excessive deflection. Several other stations along this pipe were at or above the allowable deflection of 5 percent. It is assumed the deflection at these stations were also caused by construction traffic. It should be noted that none of the excessive deflections increased over time or caused a failure of the pipe structure. No end section damage was noted during any of the surveys.

Table 3: 24 Inch Pipe, West End, Station 283+35

Station	Percent Deflection, **1996**	Percent Deflection, **2003**	Percent Deflection, **2012**	Percent Deflection, **Average**
0	1.5	2.0	0.0	1.2
10	-5.0	-4.0	-3.5	-4.2
20	-10.5	-8.0	-9.5	-9.3
30	-8.0	-5.0	-5.0	-6.0
40	-4.5	-1.0	-3.5	-3.0
50	-6.0	-4.0	-5.0	-5.0
60	-3.5	-1.0	-2.5	-2.3
70	0.5	-0.5	0.5	0.2

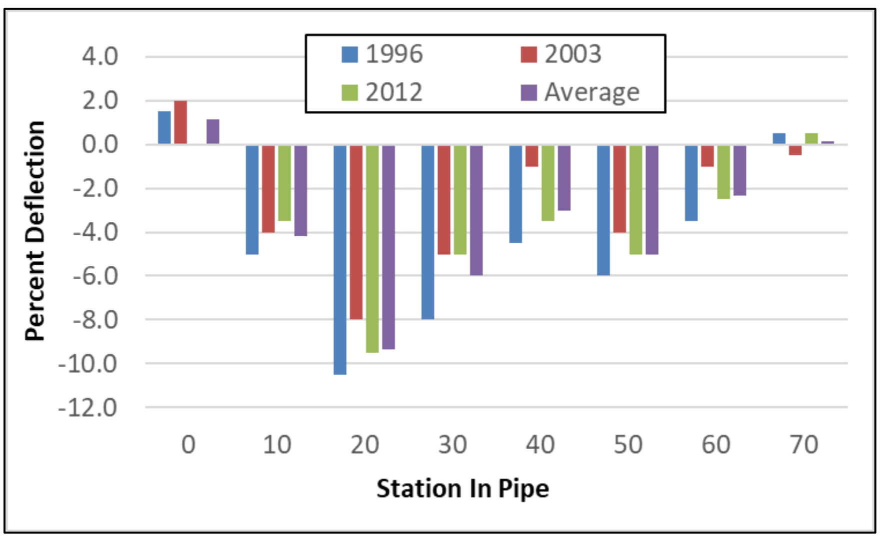


Figure 3: 24 Inch Pipe, West End, Station 283+35

Over the time of observation, the pipe diameters varied from year to year at any given station in the pipes. The variations in the pipe deflection measurements are most likely a combination of the bedding support and the pipe moving somewhat under the traffic on the flexible pavement, and the actual equipment and process used to measure the pipe deflections. Figure 4 and Figure 5 show the equipment used for the diameter measurement collection. A tripod with short removeable legs was developed to allow the level to be set up at extremely low "height of instrument" and an engineer's rule was used as a level rod. The average deflection for each station for each pipe was determined in an effort to smooth the data and determine survey errors.

There appears to be two survey errors in the data. One is the 2012 invert reading at Station 60 for the 24-inch pipe on the east end of the project, the other is the 2003 flow line reading at Station 70 for the 30-inch pipe. The average deflection values for the two stations does not include the data errors. Other stations appeared to have survey errors but could not be verified and were of a smaller magnitude.

Figure 4: Special Tripod for Level and Engineers Rule

Figure 5: Level Attached to the Tripod

Chapter 3: Summary

The PE pipes have held up well over the last 25 years as shown in the surveying data. There were also very few cracks in the pipes. The west pipe which suffered minor damage to it has also held up well as the percent deflection has dropped from 10.5 to 8.

Historically there have been construction and material problems with corrugated steel and aluminized pipe as has been noted in KDOT reports by Stratton et al. (1990) and by Tucker-Kulesza et al. (2019). Also there have been two significant issues with damage to concrete pipe; one during 1994 through 1996 on the extension of the US 75 four lane north of Topeka, Kansas. During this construction a number of concrete pipelines were thought to be damaged by construction traffic. In particular, by loaded earth movers running over the pipe before there was appropriate cover to protect the pipe. Some flow line and invert cracking were noted but it was determined that the damage was not excessive, and any repair method would be short lived and ineffective. Also, during the spring and summer of 2003, US 73 was reconstructed; 2003 was a particularly wet year. Much of the construction was done under wet conditions and pipe bedding was a problem. As was KDOT's standard, concrete pipe was used for drainage. Poor bedding and construction traffic caused the pipe sections to move, causing cracking and bell damage.

Chapter 4: Conclusions

Evaluating the data indicates that the use of HDPE pipe is a viable alternative to concrete and corrugated steel and aluminum pipe. Bedding specs must be followed, and cover requirements must be adhered to during construction. Experience indicates that any pipe material is vulnerable to damage during the construction period and concrete, steel, and aluminum can suffer long-term deterioration due to runoff conditions.

End sections were shown to be a problem as the HDPE end sections were susceptible to damage from mowers. Better end sections should be developed or either concrete, steel, or aluminum end sections should be substituted.

Chapter 5: References

Stratton, F. W., Frantzen, J. A., & Meggers, D. A. (1990). *Cause of accelerated deterioration of corrugated metal pipe installed after 1974* (Report No. KS-90/3). Topeka, KS: Kansas Department of Transportation.

Tucker-Kulesza, S., Augustine, L., Parameswaren, P., & Crowder, A. (2019). *Galvanized and aluminum pipe durability field review and evaluation* (Report No. KS-19-02). Topeka, KS: Kansas Department of Transportation.

Appendix A: ADS N-12 HP 12” - 60” Pipe Specification (ADS, Inc., Drainage Handbook)

See next page.

ADS N-12® HP 12”- 60” PIPE SPECIFICATION

Scope

This specification describes 12- through 60-inch (300 to 1500 mm) ADS N-12 HP pipe for use in gravity-flow storm drainage applications.

Pipe Requirements

- 12- through 30-inch (300 to 750 mm) pipe shall have a smooth interior and annular exterior corrugations and meet or exceed ASTM F2736 and AASHTO MP-21-11
- 36- through 60-inch (900 to 1500 mm) pipe shall have a smooth interior and annular exterior corrugations and meet or exceed ASTM F2881 and AASHTO MP-21-11
- Manning’s “n” value for use in design shall be 0.012

Joint Performance

Pipe shall be joined with a gasketed integral bell & spigot joint meeting the requirements of ASTM F2736 and F2881, for the respective diameters.

12- through 60-inch (300 to 1500 mm) shall be watertight according to the requirements of ASTM D3212. Spigots shall have gaskets meeting the requirements of ASTM F477. Gasket shall be installed by the pipe manufacturer and covered with a removable, protective wrap to ensure the gasket is free from debris. A joint lubricant available from the manufacturer shall be used on the gasket and bell during assembly.

12- through 60-inch (300 to 1500 mm) diameters shall have a reinforced bell with a polymer composite band installed by the manufacturer.

Fittings

Fittings shall conform to ASTM F2736, ASTM F2881 and AASHTO MP-21-11, for the respective diameters. Bell & spigot connections shall utilize a spun-on, welded or integral bell and spigot with gaskets meeting ASTM F477. Bell & spigot fittings joint shall meet the watertight joint performance requirements of ASTM D3212. Corrugated couplings shall be split collar, engaging at least 2 full corrugations.

Field Pipe and Joint Performance

To assure watertightness, field performance verification may be accomplished by testing in accordance with ASTM F2487. Appropriate safety precautions must be used when field-testing any pipe material. Contact the manufacturer for recommended leakage rates.

Material Properties

Polypropylene compound for pipe and fitting production shall be impact modified copolymer meeting the material requirements of ASTM F2736, Section 4, ASTM F2881, Section 5 and AASHTO MP-21-11, Section 6.1, for the respective diameters.

Installation

Installation shall be in accordance with ASTM D2321 and ADS recommended installation guidelines, with the exception that minimum cover in traffic areas for 12- through 48-inch (300 to 1200 mm) diameters shall be one foot. (0.3 m) and for 60-inch (1500 mm) diameters, the minimum cover shall be 2 ft. (0.6 m) in single run applications. Backfill for minimum cover situations shall consist of Class 1, Class 2 (minimum 90% SPD) or Class 3 (minimum 95%) material. Maximum fill heights depend on embedment material and compaction level; please refer to Technical Note 2.04. Contact your local ADS representative or visit our website at www.ads-pipe.com for a copy of the latest installation guidelines.

Pipe Dimensions

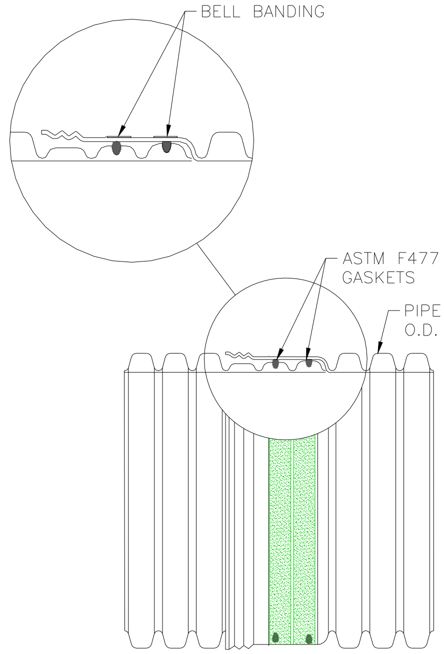
Nominal Pipe I.D. in (mm)	12 (300)	15 (375)	18 (450)	24 (600)	30 (750)	36 (900)	42 (1050)	48 (1200)	60 (1500)
Average Pipe I.D. In (mm)	12.1 (307)	14.9 (378)	18.0 (457)	24.1 (612)	30.1 (765)	35.7 (907)	41.8 (1062)	47.3 (1201)	59.3 (1506)
Average Pipe O.D. in (mm)	14.5 (368)	17.6 (447)	21.2 (538)	28.0 (711)	35.4 (899)	41.1 (1044)	47.2 (1199)	53.8 (1367)	66.5 (1689)
Minimum Pipe Stiffness * @ 5% Deflection* #/in./in. (kN/m^2)	75 (520)	60 (411)	56 (385)	50 (343)	46 (320)	40 (275)	35 (240)	35 (240)	30 (205)

* Minimum pipe stiffness values listed; contact a representative for maximum values

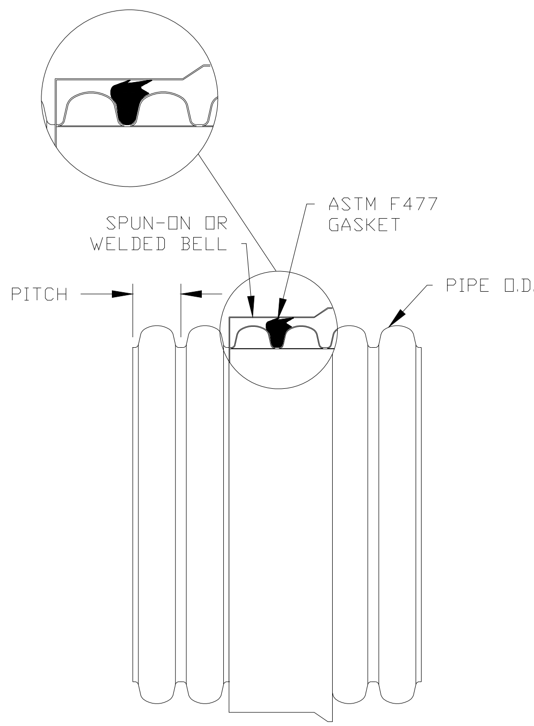
©ADS, Inc., September 2011

N-12® HP 12” – 60” PIPE JOINT SYSTEM

(Joint configuration & availability subject to change without notice. Product detail may differ slightly from actual product appearance.)



Check with a sales representative for regional availability



© ADS, Inc., September 2011

Appendix B: ADS, Inc., Construction Field Report

See next page.

KANSAS DOT PILOT PROJECT

HIGHWAY 66

CROSSROAD & STORM SEWER

HDPE

BACKGROUND

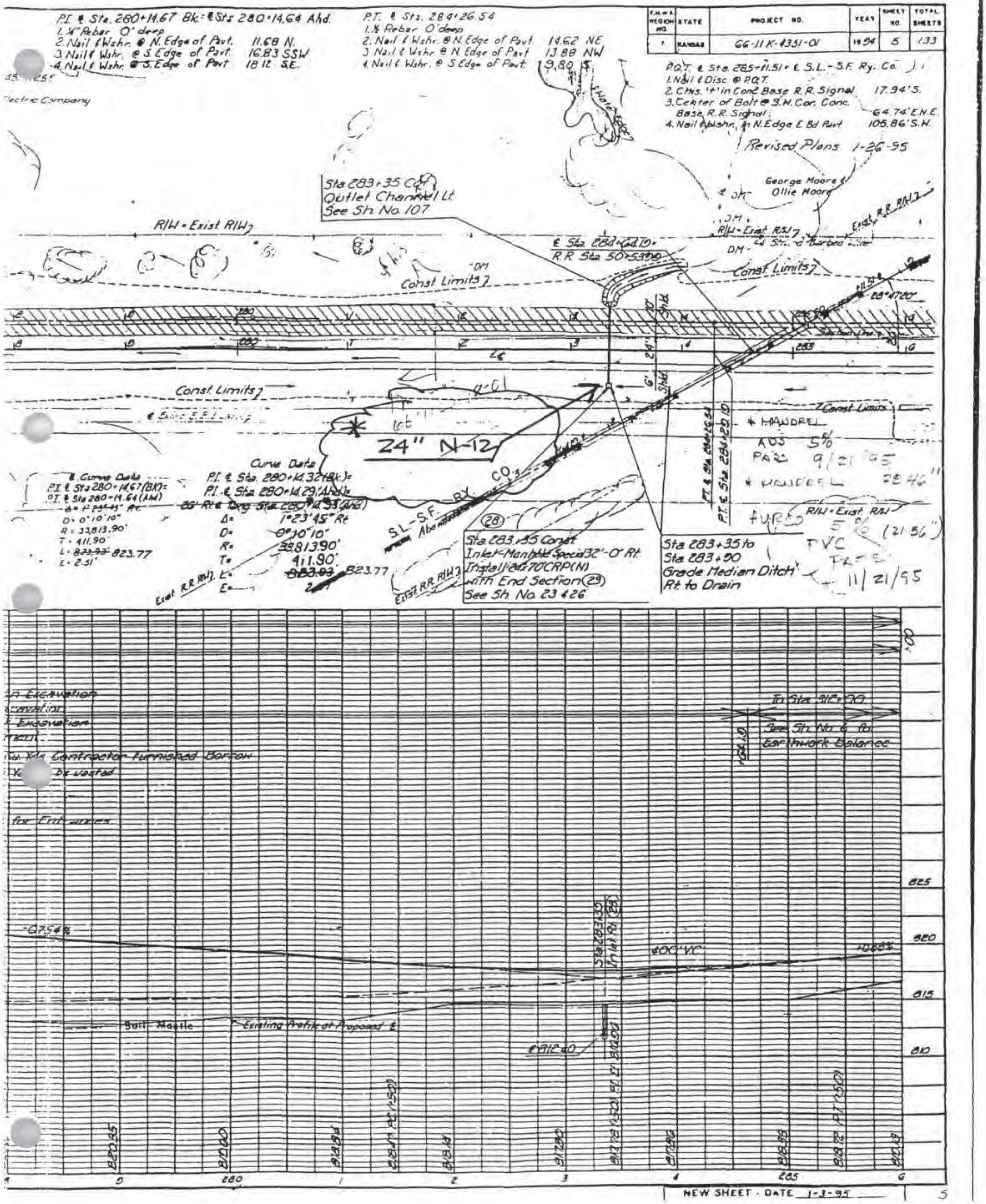
ON JUNE 1995, LA FORGE AND BUDD CONTRACTOR INSTALLED A 24” HDPE PIPE WITH SMOOTH INSIDE. THIS PIPE WAS THE FIRST CROSSROADS INSTALLMENT OF POLYETHYLENE PIPE UNDER A MAJOR HIGHWAY (HWY K-66) ALLOWED BY KDOT.

IN THE SAME PROJECT THE CONTRACTOR ALSO INSTALLED 30” AND 24” HDPE UNDER THE DAME LOAD CONDITIONS.

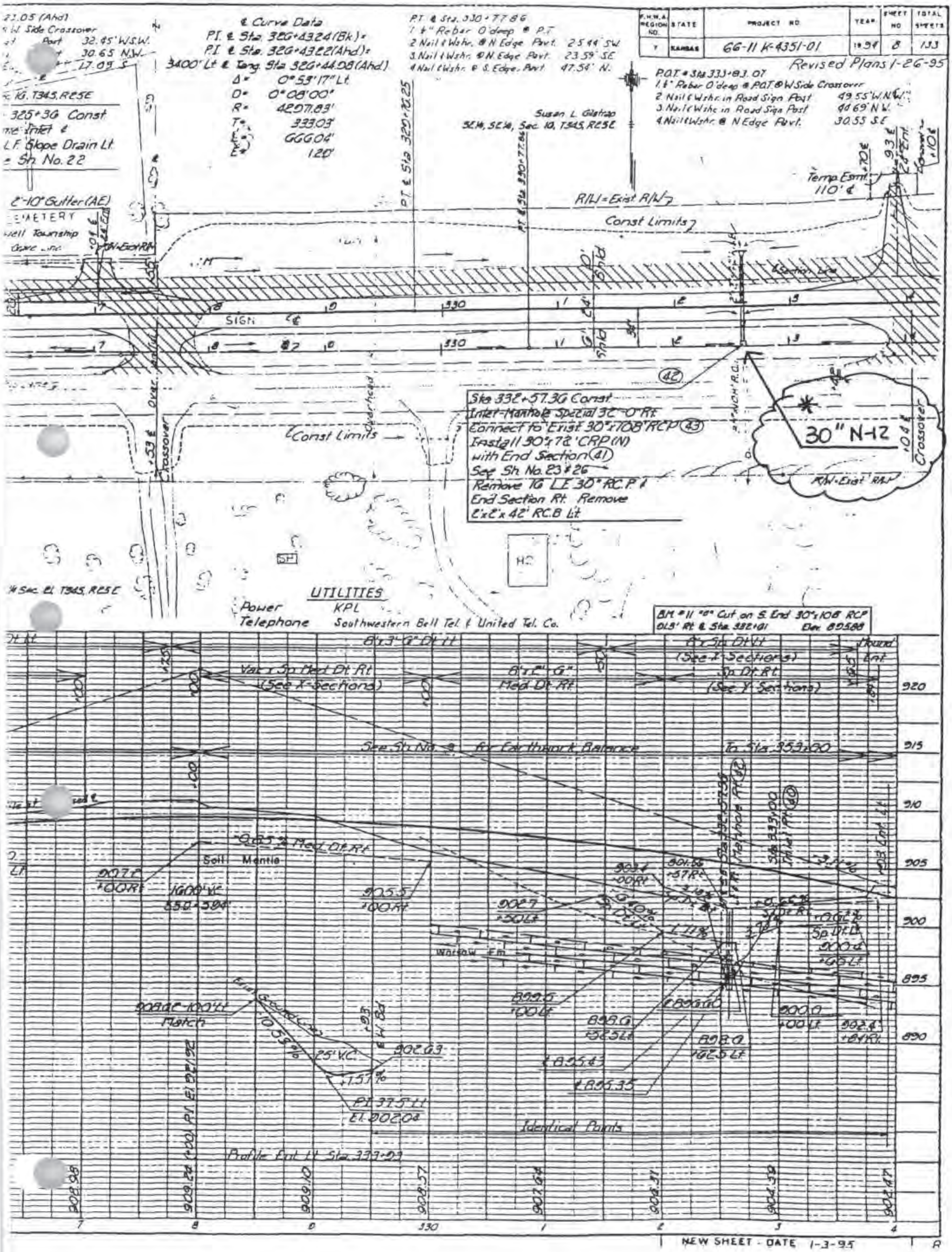
ON SEPTEMBER 1995, JOHN WHITWOOD (ADS), IGNACIO PEREZ (ADS), BOB GUDGEN (KDOT), JACK AMERSHACK (KDOT) VISUALLY INSPECTED THE PIPES AND PERFORMED DEFLECTION TESTS.

TO PERFORM THE TEST A 5% MANDREL WAS USED TO TEST THE 24” HDPE PIPE. A DEFLECTOMETER WAS USED TO TEST THE 30” PIPE. THE TEST RESULTS ARE INCLUDE ON THIS REPORT. THE MATERIAL USED FOR BEDDING AND BACKFILL WAS 1” MINUS WITH 12% PASSING SIEVE 200, THIS MATERIAL WAS MECHANICALLY COMPACTED.

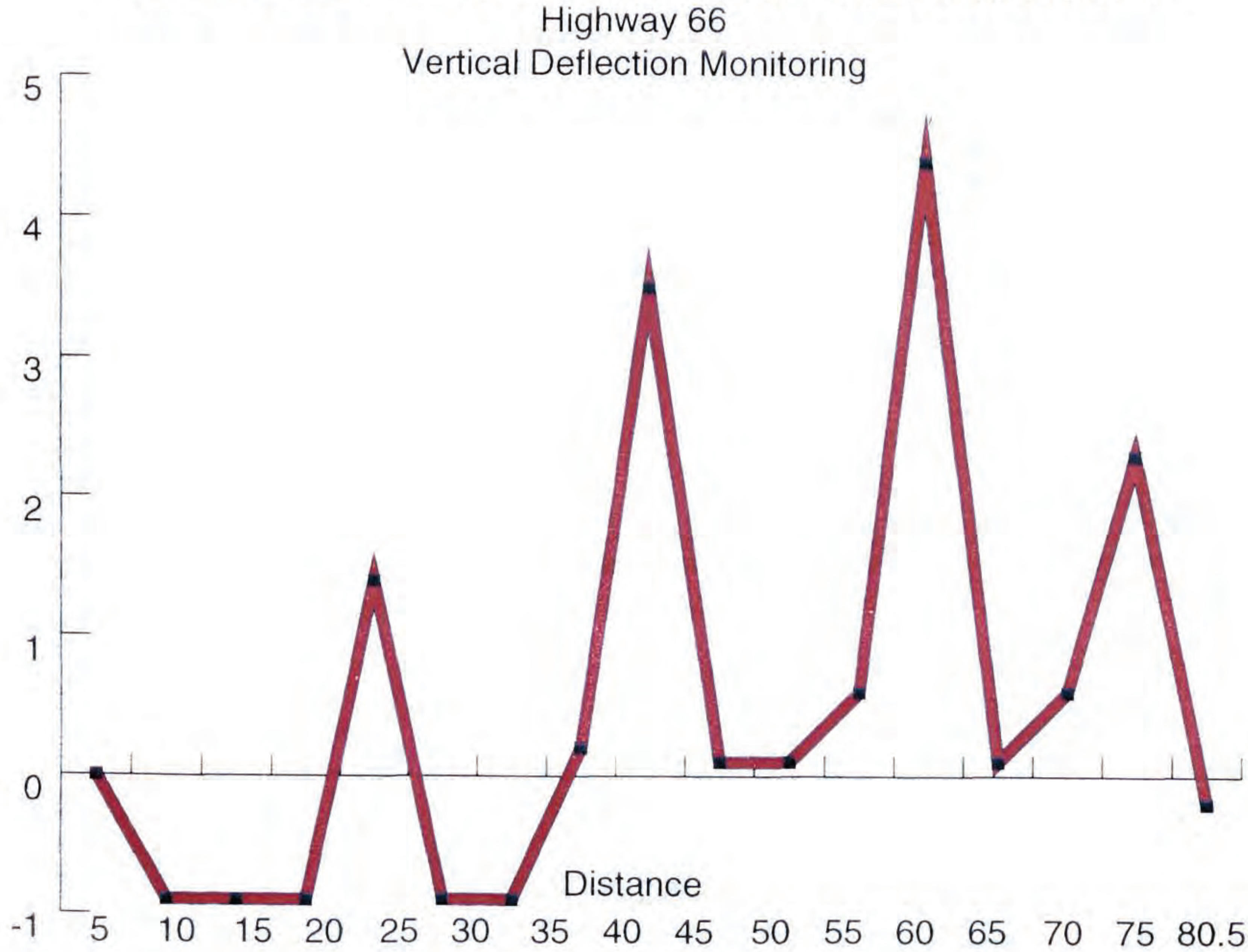
THE INSTALLATION OF THE 30” PIPE FOLLOWED THE SAME PROCEDURE THAN RCP PIPE WHEN INSTALLED UNDER EMBANKMENT CONDITIONS “NO TRENCH”. THE SIDE SUPPORT MATERIAL WAS PLACED AROUND THE PIPE AND CO0MPACTED BEFORE CONTRUCTION LOADS WERE ALLOWED TO DIRVE OVER.

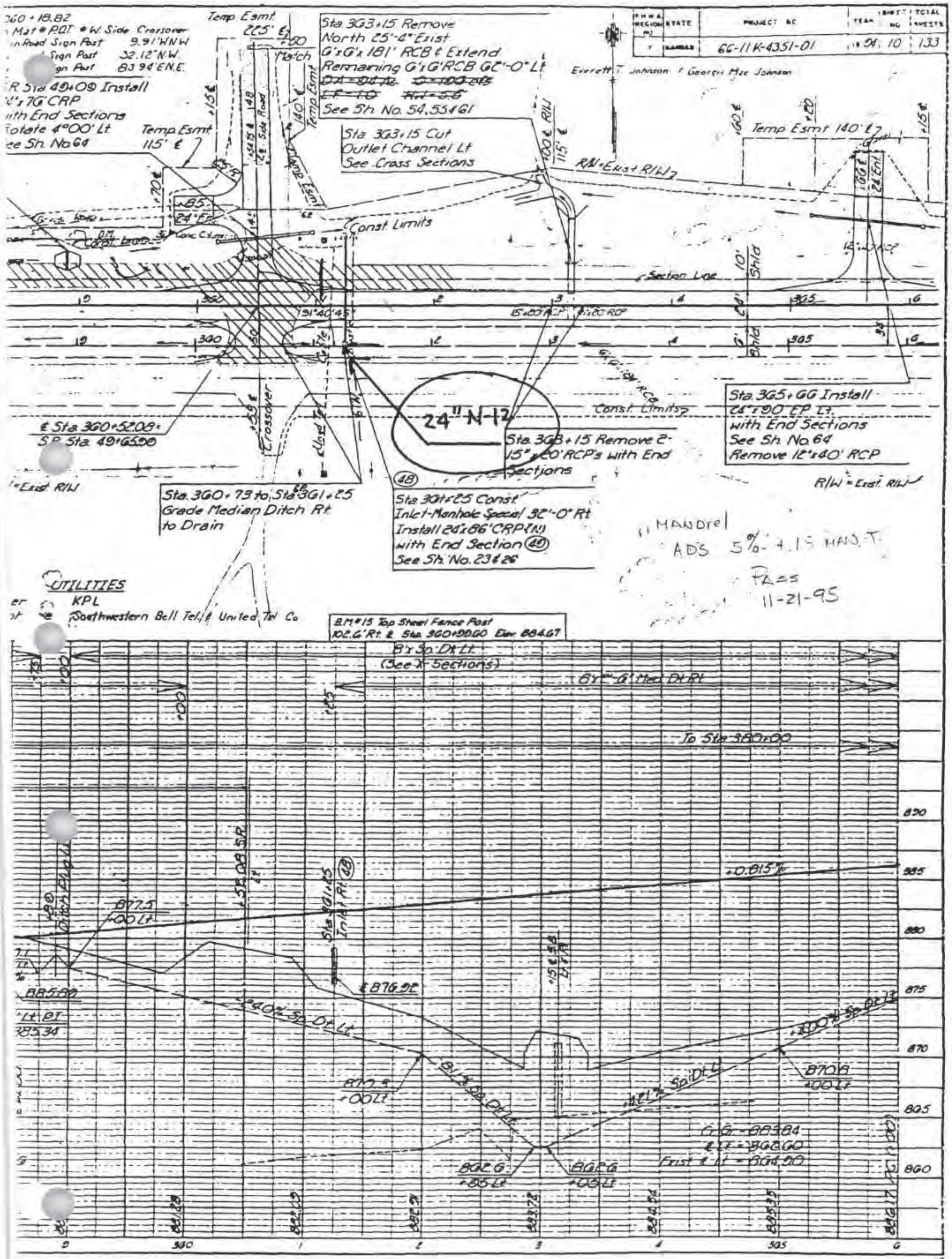

F.H.W.A. REGION NO. | STATE | PROJECT NO. | YEAR | SHEET NO. | TOTAL SHEETS
7 | KANSAS | 66-11 K-4351-01 | 1994 | 5 | 133
P.I. ℄ Sta. 280+14.67 Bk.=℄ Sta. 280+14.64 Ahd.
1. ½" Rebar O' deep
2. Nail & Wshr. @ N. Edge of Pavt. 11.68 N.
3. Nail & Wshr. @ S. Edge of Pavt. 16.83 SSW
4. Nail & Wshr. @ S. Edge of Pavt. 18.12 S.E.
P.T. ℄ Sta. 284+26.54
1. ½ Rebar O' deep
2. Nail & Wshr. @ N. Edge of Pavt. 14.62 NE
3. Nail & Wshr. @ N. Edge of Pavt. 13.88 NW
4. Nail & Wshr. @ S Edge of Pavt. 9.80
P.O.T. ℄ Sta. 285+11.51 = ℄ S.L.-S.F. Ry. Co.
1. Nail & Disc @ P.O.T.
2. Chis. '+' in Conc. Base R.R. Signal 17.94'S.
3. Center of Bolt @ S.W. Cor. Conc. Base R.R. Signal 64.74' E.N.E.
4. Nail & Wshr. in N. Edge E Bd Pavt 105.86' S.W.
Revised Plans 1-26-95
George Moore & Ollie Moore
Sta 283+35 C&F Outlet Channel Lt. See Sh. No. 107
R/W = Exist R/W
Const Limits
℄ Sta. 284+64.19 = R.R. Sta. 50+53.50
Exist. R.R. R/W
Const. Limits
24" N-12
* MANDREL
ADS 5%
PASS 9/21/95
* MANDREL
AVRED 5% (21.56")
PVC
PASS
11/21/95
Curve Data
P.I. ℄ Sta. 280+14.32 (Bk.)=
P.I. ℄ Sta. 280+14.29 (Ahd.)=
Δ= 1°23'45" Rt
D= 0°10'10"
R= 33,813.90'
T= 411.90'
L= 823.77
S.L.-S.F. RY. CO.
Sta 283+35 Const Inlet-Manhole Special 32'-0" Rt. Install 24" CRP(N) with End Section (29) See Sh. No. 23 & 26
Sta 283+35 to Sta 283+90 Grade Median Ditch Rt. to Drain
P.T. ℄ Sta. 284+26.54
P.T. ℄ Sta. 284+20.10
R/W = Exist. R/W
To Sta. 311+90
See Sh. No. 6 for Earthwork Balance
Contractor Furnished Borrow
-0.754%
400' VC
+0.88%
Existing Profile at Proposed ℄
825
820
815
810
280
285
NEW SHEET - DATE 1-3-95

CAT

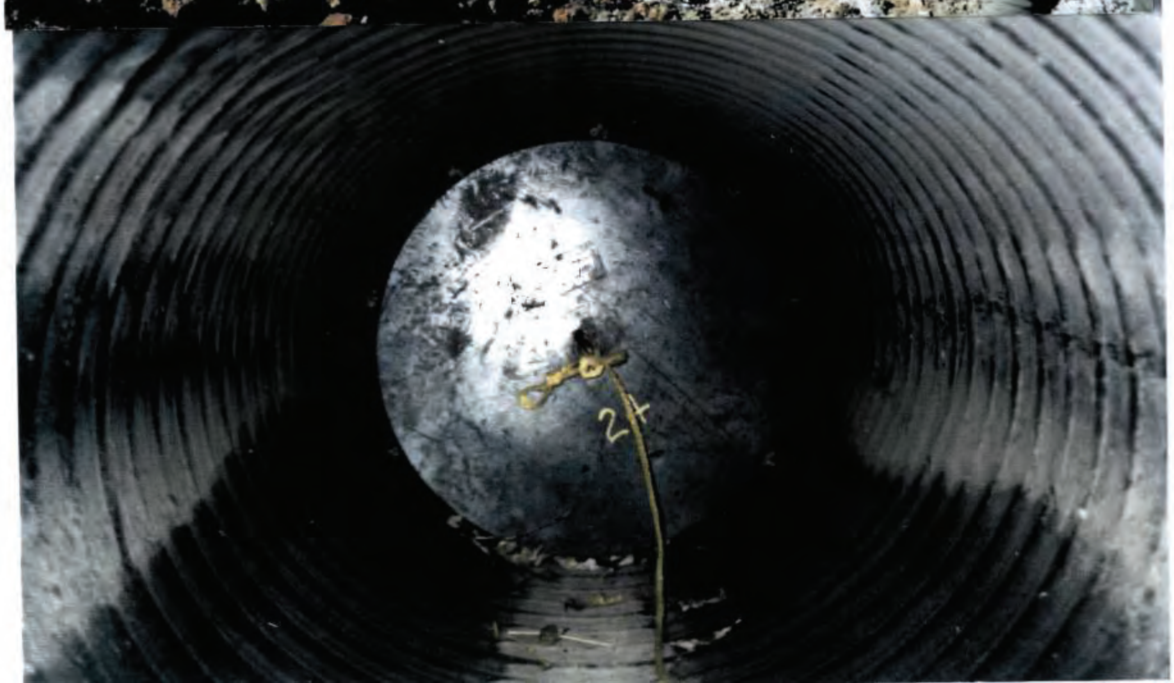

KANSAS
66-11 K-4351-01
1994
8
133
Revised Plans 1-26-95
℄ Curve Data
P.I. ℄ Sta. 326+43.24(Bk)=
P.I. ℄ Sta. 326+43.22(Ahd)=
3400' Lt ℄ Tang. Sta 326+44.08(Ahd)
Δ= 0°53'17" Lt.
D= 0°08'00"
R= 42971.83'
T= 333.03'
L= 666.04'
E= 1.20'
P.T. ℄ Sta. 330+77.86
Susan L. Gilstrap
POT ℄ Sta 333+83.07
Sta 332+57.36 Const.
Inlet-Manhole Special 32'-0" Rt.
Connect to Exist. 30"x108' RCP (43)
Install 30"x72' CRP(N)
with End Section (41)
See Sh. No. 23 & 26
Remove 16 LF 30" R.C.P. &
End Section Rt. Remove
2'x2'x42' RCB Lt.
30" N-12
Const Limits
R/W=Exist R/W
Crossover
SIGN
UTILITIES
Power KPL
Telephone Southwestern Bell Tel. & United Tel. Co.
See Sh. No. 9 for Earthwork Balance
Identical Points
Profile Ent Lt Sta. 333+03
Soil Mantle
Warsaw Fm.
NEW SHEET - DATE 1-3-95

Kansas DOT
30" HDPE Crossroad Installation




66-11 K-4351-01
54
10
133
Everett T. Johnson & George Mae Johnson
Sta. 363+15 Remove North 25'-4" Exist. 6'x6'x181' RCB & Extend Remaining 6'x6' RCB 62'-0" Lt
See Sh. No. 54, 55 & 61
Sta. 363+15 Cut Outlet Channel Lt See Cross Sections
Temp Esmt 225' ℄
Temp Esmt 115' ℄
Temp Esmt 140' ℄
Const. Limits
Section Line
24" N-12
Sta. 363+15 Remove 2-15" x 20' RCP's with End Sections
Sta. 365+66 Install 26" x 90' EP Lt. with End Sections See Sh. No. 64 Remove 12" x 40' RCP
℄ Sta. 360+52.08 = S.R. Sta. 49+65.50
Sta. 360+73 to Sta. 361+25 Grade Median Ditch Rt. to Drain
Sta. 361+25 Const. Inlet-Manhole Special 32'-0" Rt. Install 24" x 86' CRP (N) with End Section (49) See Sh. No. 23 & 26
MANDREL
ADS 5% - 4.15 MAND. T.
PASS
11-21-95
UTILITIES
KPL
Southwestern Bell Tel. & United Tel. Co.
B.M. #15 Top Steel Fence Post 102.6' Rt. ℄ Sta. 360+90.60 Elev. 884.67
8' x 5 Dt Lt. (See X-Sections)
To Sta. 380+00
+0.815%
Crossover
R/W = Exist. R/W
890
885
880
875
870
865
860
360
1
2
3
4
365
6


ROAD CLOSED


24

9.3 CULVERT DESIGN

9.3.1 Manning friction factors (n) of Big 'O' heavy duty pipes

Hydraulic capacity tests of Big 'O' heavy duty pipes under outlet control conditions with the outlet submerged were carried out at the LaSalle Hydraulic Laboratory in Ville LaSalle, Quebec, by Bolduc (1983). The set-up is shown in Appendix C.

In order to interpolate what can be expected between the measured values, a power regression analysis was performed on the collected data. The resulting equation can be written in the form:

$$Q = \frac{KS^B}{1000} \qquad (9.23)$$

where Q is the discharge in m³/s

S is the hydraulic gradient in percent

K and B are constants for each pipe determined from experimental data and are given in Table 9.1.

Manning's coefficients have been calculated using Manning's equation and discharges obtained from these hydraulic tests.

It is recommended to use the values given in Table 9.2 in design of culvert pipe. However, a smoothness coefficient ($m = 1/n$) rather than a roughness coefficient in calculating the discharge capacity of a pipe may be used. Smoothness coefficients are also given in Table 9.2.

The discharge capacity of the pipe can then be calculated as

$$Q = \frac{A R_h^{2/3} S^{1/2}}{n} = m A R_h^{2/3} S^{1/2} \qquad (9.24)$$

using the same definitions and units for the symbol letters as defined previously.

Table 9.1 Constants K and B corresponding to each diameter of pipe

Nominal inside diameter mm	K	B	$Q = KS^B$
300	77.5	0.54	
400	111.5	0.57	
450	167.3	0.54	
500	249.7	0.51	
600	430.0	0.51	

See Equation 9.18

Table 9.2 Recommended values of Manning's friction factor to be used in design of culvert pipe.

Nominal inside diameter mm	Manning's n	Smoothness coefficient 1/n
300	0.017	58.8
400	0.026	38.5
450	0.023	43.5
500	0.020	50.0
600	0.018	55.6

9.3.2 Darcy-Weisbach friction factors (f) of Big 'O' heavy duty pipe

Using a coefficient of proportionality, f.
Darcy, Weisbach and others proposed equations of the form

$$H_f = f \times \frac{L}{D}\frac{V^2}{2g} \quad \text{(9.25)}$$

to determine the head loss caused by pipe friction (H_f) in long, straight, uniform pipes.

where f = Darcy-Weisbach friction factor
L = length of the pipe, m
D = diameter of the pipe, m
V = average velocity, m/s
g = acceleration of gravity, 9.8 m/s²

The Reynold's number and Darcy-Weisbach friction factor have been calculated for each measurement using the following equations:

$$f = \frac{H_f \times D \times 2g}{L \times V^2} \quad \text{(9.26)}$$

where H_f, D, g, L and V were previously defined

$$\text{and } R_n = \frac{V \times D}{\nu} \quad \text{(9.27)}$$

where D = diameter of the pipe, m
V = average velocity, m/s
ν = kinetic molecular viscosity, m²/s, see Appendix D

The results of R_n vs. f are shown in Fig. 9.14

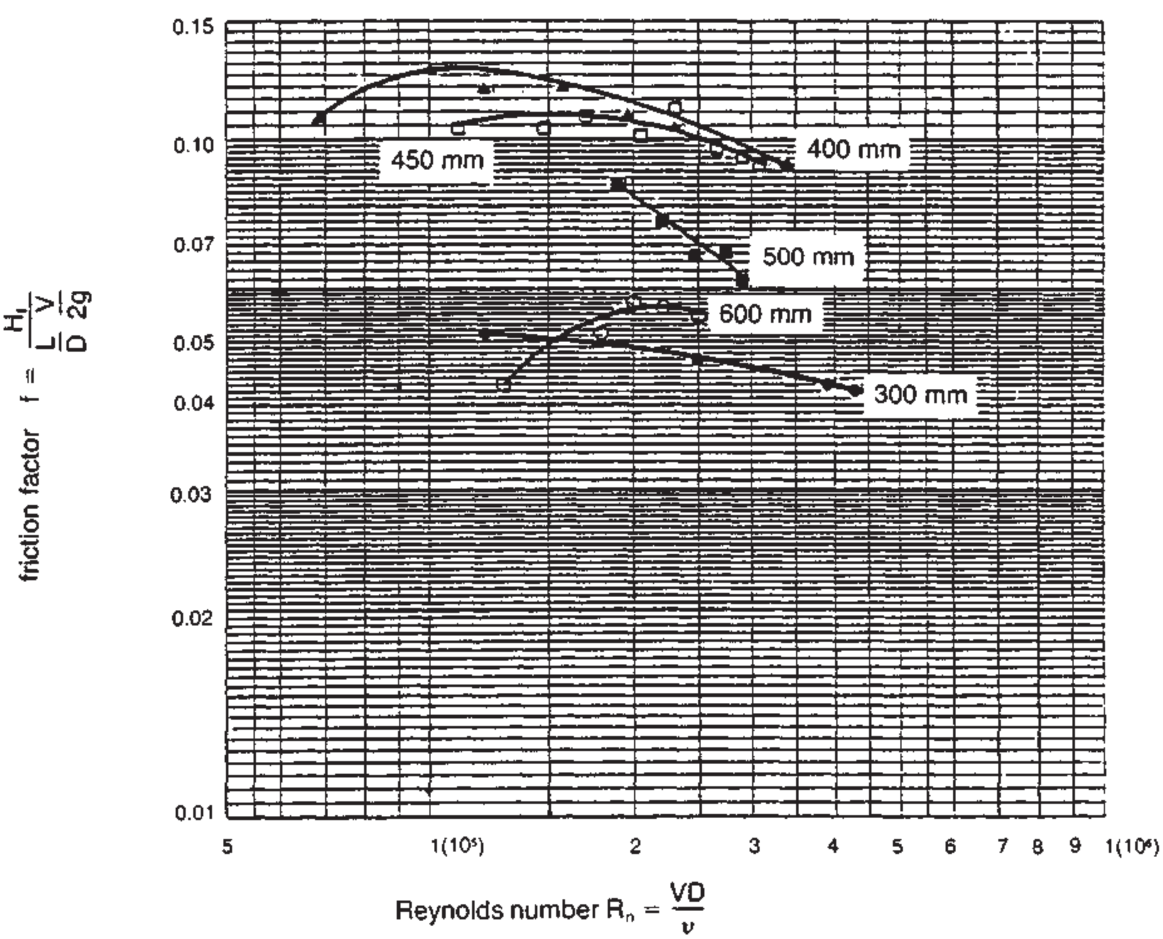


Figure 9.14 Diagram of Darcy-Weisbach friction factor vs. Reynolds number for diameter of pipes as indicated.

9.3.3 Critical Depth – (d_c)

Figure 9.15 gives the critical depth of flow vs. the discharge Q in Big 'O' heavy duty pipes. The reader is referred to section 9.2.2.3.

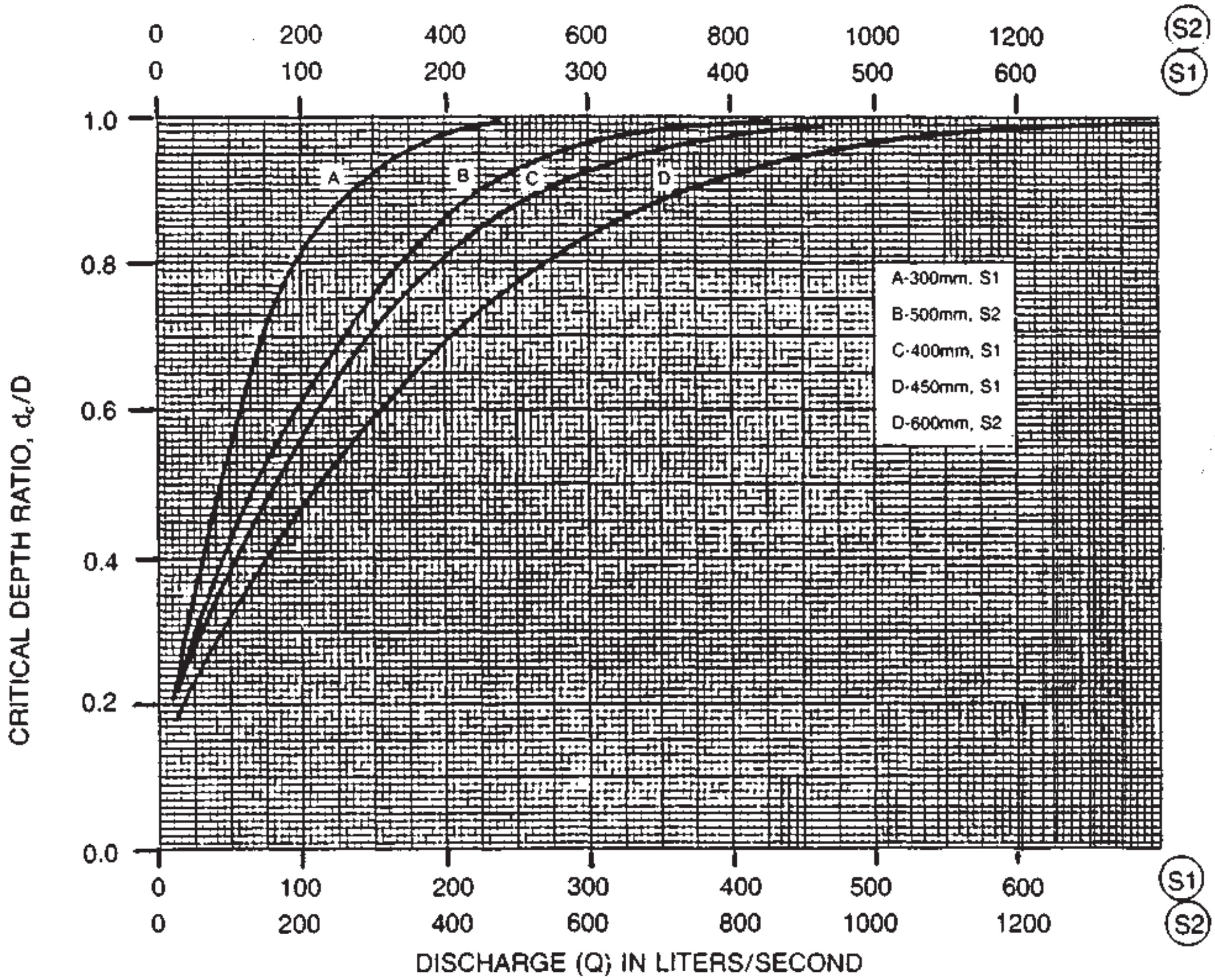


Figure 9.15 Critical depth of flow in Big 'O' heavy duty pipes.

9.3.4 Hydraulic graphs for Culvert Design

9.3.4.1 Culverts Flowing with Inlet Control

1) Headwater Depth (HW)

Figures 9.16, 9.17 and 9.18 were plotted from the data obtained from the nomographs prepared by Herr and Bossy (1965). It should be noted that the headwater (HW) was previously defined as the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools and the difficulty in determining the velocity head for all flows, the water surface and the energy line were assumed to be coincident in the elaboration of these nomographs. Thus the headwater depths given by the inlet control charts can be higher than will occur. Therefore, headwater depths (HW) obtained from Figs. 9.16 to 9.18 are conservative values.

9.3.4.2 Culverts Flowing with Outlet Control

1) Discharge capacity (Q) of a culvert flowing with outlet control

The capacity of a culvert under pipe flow conditions is given by:

$$Q = \frac{A\sqrt{2gh}}{\sqrt{1+K_e+K_b+K_cL}} \quad (9.28)$$

where g = acceleration of gravity, 9.8 m/s²
K_e = entrance loss coefficient, see Table 9.4
K_c = the head loss coefficient for circular conduits flowing full, see Table 9.3 and Appendix B
K_b = friction loss coefficient at bends. Most culverts do not have bends, K_b can often be omitted
A = cross-sectional area of the pipe, m²
H = head loss through the structure, m
Q = discharge, m³/s

Table 9.3 Head loss coefficient K_c for Big 'O' pipes flowing full					
Pipe diameter, mm	300	400	450	500	600
Manning friction Factor 'n'	0.017	0.026	0.023	0.020	0.018
Head loss coefficient "K_c', m^{-1}	0.179	0.285	0.191	0.125	0.080

Table 9.4 Entrance loss coefficients, k_e	
Inlet end of culvert	Coefficient, k_e
Entrance is projecting from fill with no headwall	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered (beveled) to conform to fill slope	0.7

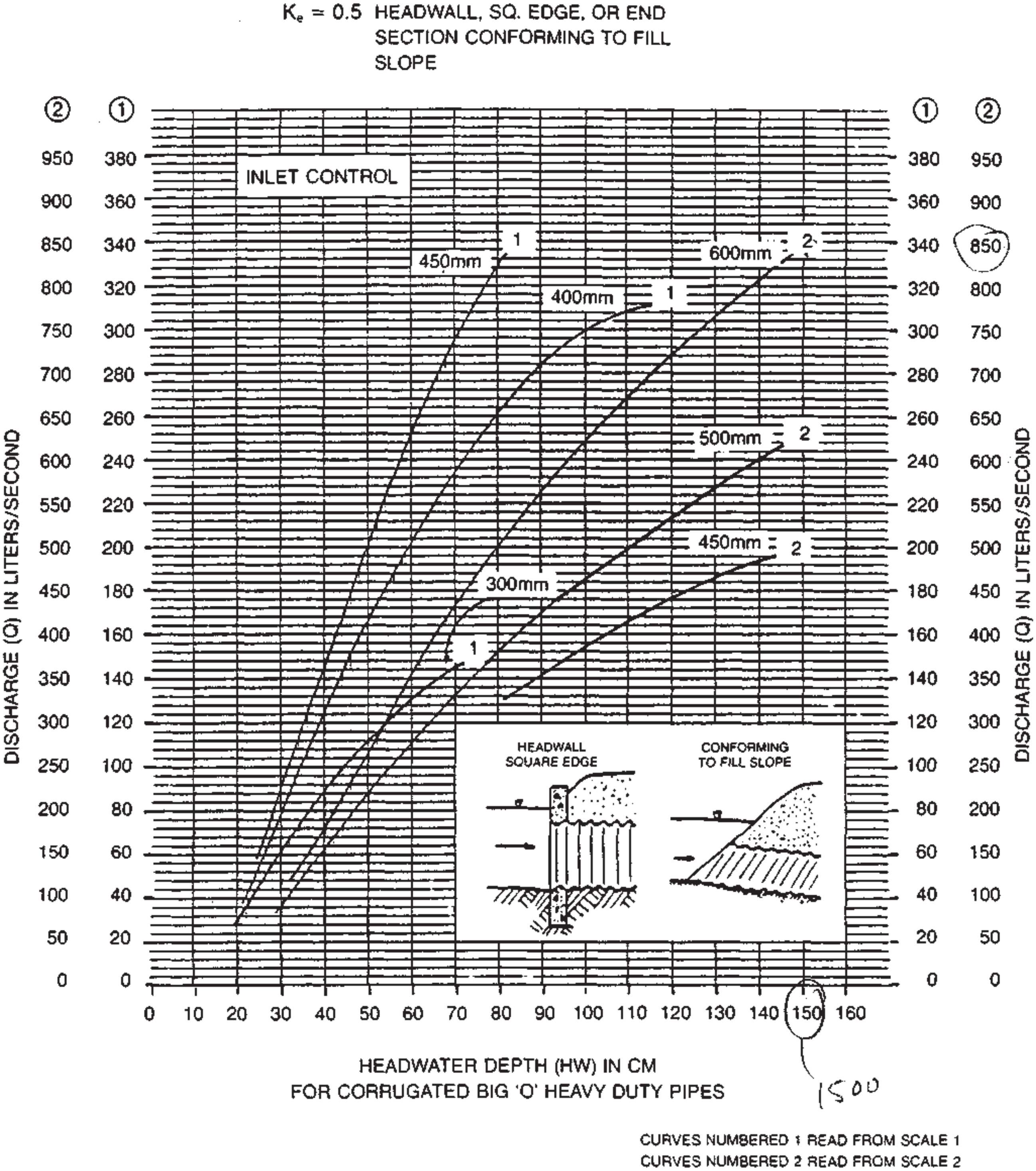
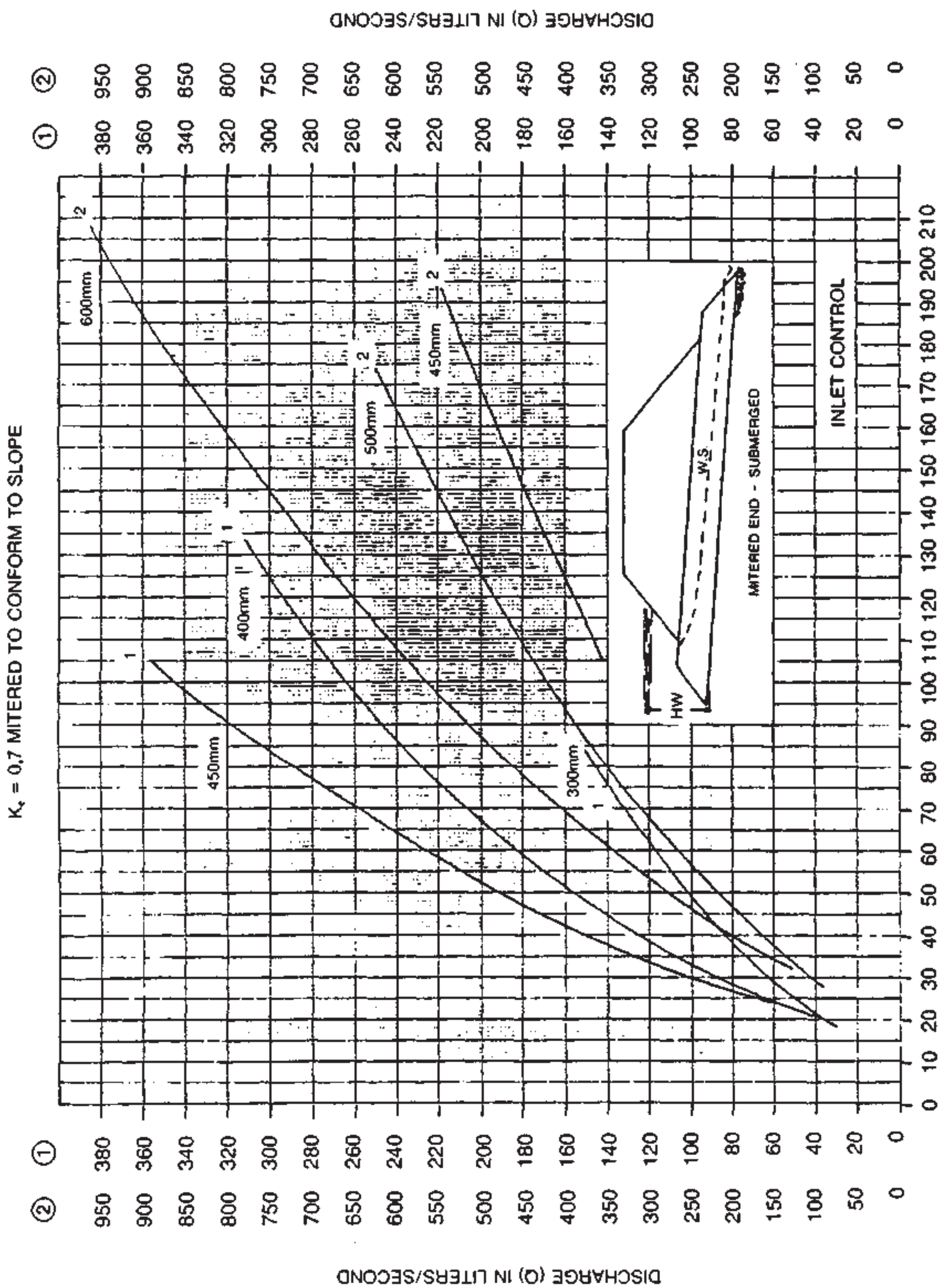


Figure 9.16 Headwater depth (HW) vs. flow discharge (Q) for Big 'O' heavy duty pipes; inlet control (k_e = 0.5)



CURVES NUMBERED 1 READ FROM SCALE 1
CURVES NUMBERED 2 READ FROM SCALE 2

Figure 9.17 Headwater depth (HW) vs. Flow Discharge (Q) of Big 'O' Heavy Duty Pipes Flowing with Inlet Control (k_e = 0.7)

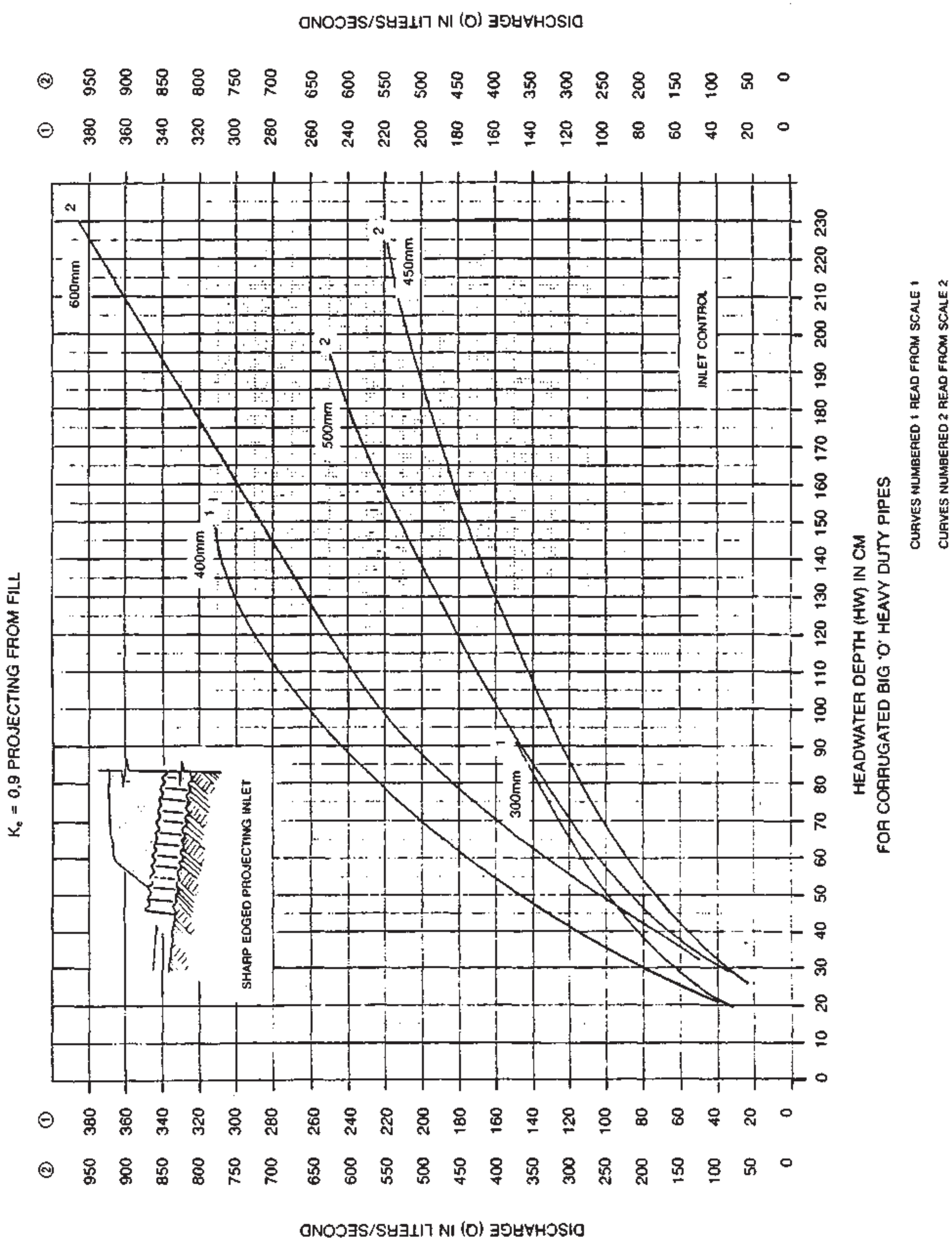


Figure 9.18 Headwater Depth (HW) vs. flow discharge (Q) of Big 'O' Heavy Duty Pipes flowing with inlet control (k_e 0.9)

2) Head Loss H (Outlet Control)
H is computed by equation (9.17) or found from the Figs. 9.19 to 9.21 entitled "Head Loss (H) in cm vs. Discharge (Q) in liters/second for Big 'O' heavy duty pipes – flowing full-outlet control". These figures can be used if: $6 \leq L \leq 12$ meters, interpolation being allowed. For other lengths equation (9.17) can be used but table 9.5 provides shortcuts and makes computations a lot easier.
From equation 9.14:

$$H = H_v + H_e + H_f$$

H_v, H_e and H_f can be expressed as:

$$H_v = C_v \times Q^2 \quad (9.29)$$

$$H_e = C_e \times Q^2 \times K_e \quad (9.30)$$

$$H_f = C_f \times Q^2 \times L \quad (9.31)$$

where K_e = entrance loss coefficient, see Table 9.4
where Q = flow discharge, in liters/second
L = length of the pipe, in meters
C_v, C_e, C_f are given in Table 9.5.
The losses H_v, H_e and H_f are in centimeters

Table 9.5. Values of coefficient C_v, C_e and C_f to use in equation (9.29), (9.30) and (9.31).

Big 'O' nominal diameter mm	Q Range of Q l/s	$C_v \times 10^4$	$C_e \times 10^4$	$C_f \times 10^4$
300	20-64	10.21	10.21	1.800
300	65-150	10.22	10.22	1.600
400	40-74	3.21	3.21	0.960
400	75-300	3.22	3.22	0.800
450	50-149	2.02	2.02	0.380
450	150-400	2.02	2.02	0.350
500	20-500	1.32	1.32	0.164
600	100-650	0.64	0.64	0.056

Examples of Head Loss (H) Computations using Short Cuts

Examples: Find the head loss (H) for the following BIG 'O' heavy duty pipes flowing with outlet control, in given hydraulic conditions.

1) $L = 11.2\text{m}$, $D = 450$ mm, $Q = 172$ l/s, $K_e = 0.7$

$$H_v = \underbrace{2.02 \times 10^{-4}}_{C_v} \times \underbrace{(172)^2}_{Q^2} = 5.98 \text{ cm}$$

$$H_e = \underbrace{2.02 \times 10^{-4}}_{C_e} \times \underbrace{(172)^2}_{Q^2} \times \underbrace{0.7}_{K_e} = 4.18 \text{ cm}$$

$$H_f = \underbrace{0.350 \times 10^{-4}}_{C_f} \times \underbrace{(172)^2}_{Q^2} \times \underbrace{11.2}_{L} = \underline{11.60 \text{ cm}}$$

$$21.76 \text{ cm} = H$$

2) $L = 6.0$ m, $D = 500$ mm, $Q = 200$ l/s, $K_e = 0.9$

$H_v = 1.32 \times 10^{-4} \times (200)^2 = 5.28$ cm

$H_e = 1.32 \times 10^{-4} \times (200)^2 \times 0.9 = 4.75$ cm

$H_f = 0.164 \times 10^{-4} \times (200)^2 \times 6.0 = \underline{3.93 \text{ cm}}$

$H = 13.97$ cm

This result can be compared with the direct reading from Fig. 9.19 which gives $H = 14$ cm.

3) $L = 7.5$ m, $D = 500$ mm, $Q = 200$ l/s, $K_e = 0.9$

$H_v = 1.32 \times 10^{-4} \times (200)^2 = 5.28$ cm

$H_e = 1.32 \times 10^{-4} \times (200)^2 \times 0.9 = 4.75$ cm

$H_f = 0.164 \times 10^{-4} \times (200)^2 \times 7.5 = \underline{4.92 \text{ cm}}$

$H = H_v + H_e + H_f = 14.95$ cm

This can be compared with the reading obtained by interpolation from
Fig. 9.19: $D = 500$ mm, $Q = 200$ l/s, $L = 6.0 \text{ m} \rightarrow H_1 = 14$ cm
Fig. 9.20: $D = 500$ mm, $Q = 200$ l/s, $L = 9.0 \text{ m} \rightarrow H_2 = 16$ cm
For $L = 7.5$ m we interpolate linearly between H_1 and H_2 and obtain:

$H = 15.0$ cm

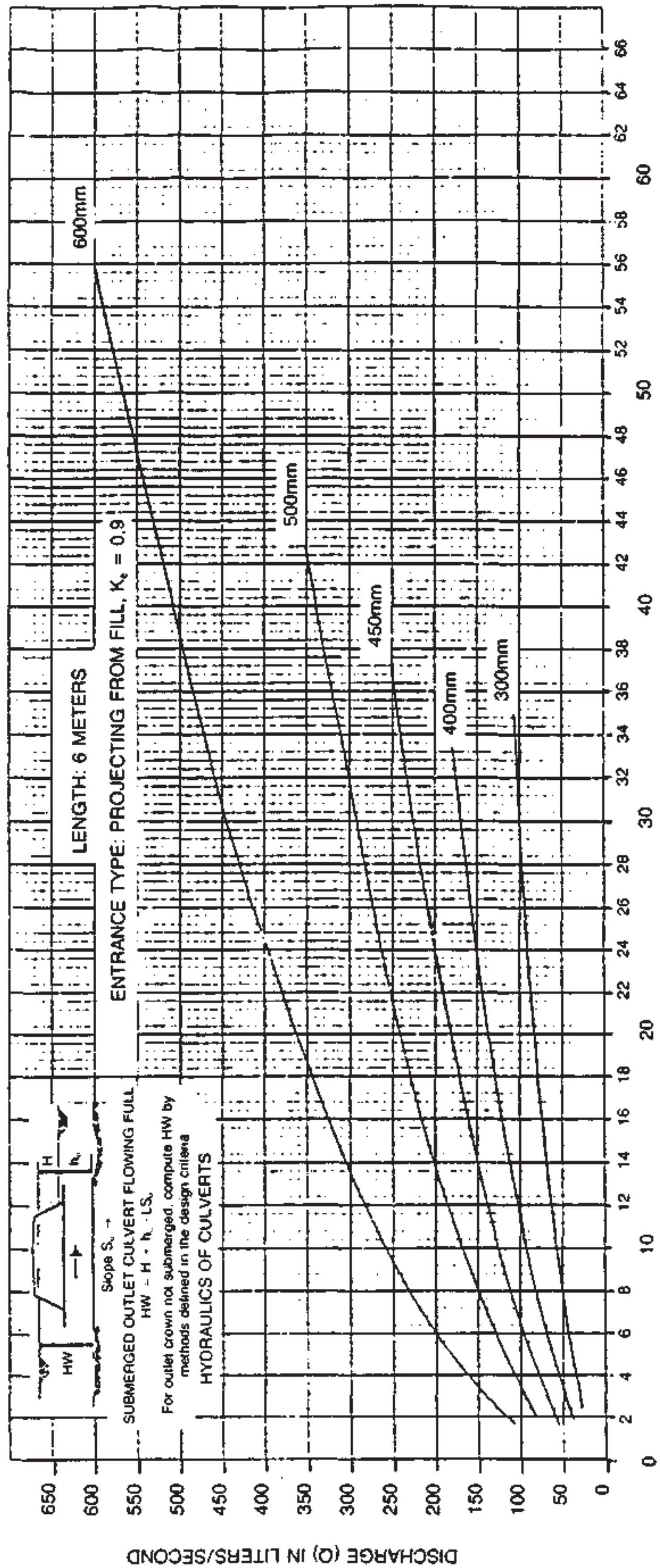


Fig. 9.19 Head loss (H) in cm vs discharge (Q) in liters/second for Big 'O' heavy duty pipes

FLOWING FULL – OUTLET CONTROL

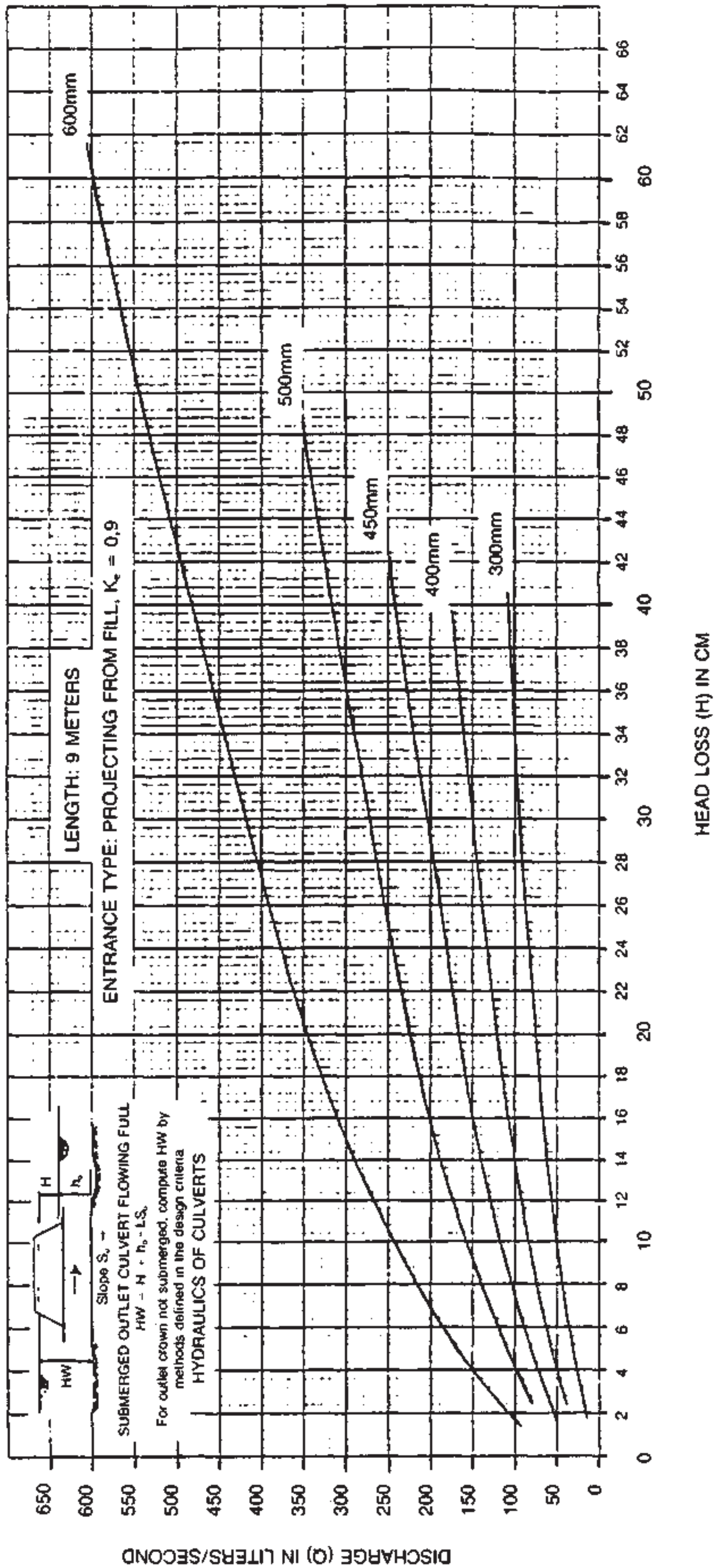


Fig. 9.20 head loss (H) in cm vs discharge (Q) in liters/second for Big 'O' heavy duty pipes

FLOWING FULL - OUTLET CONTROL

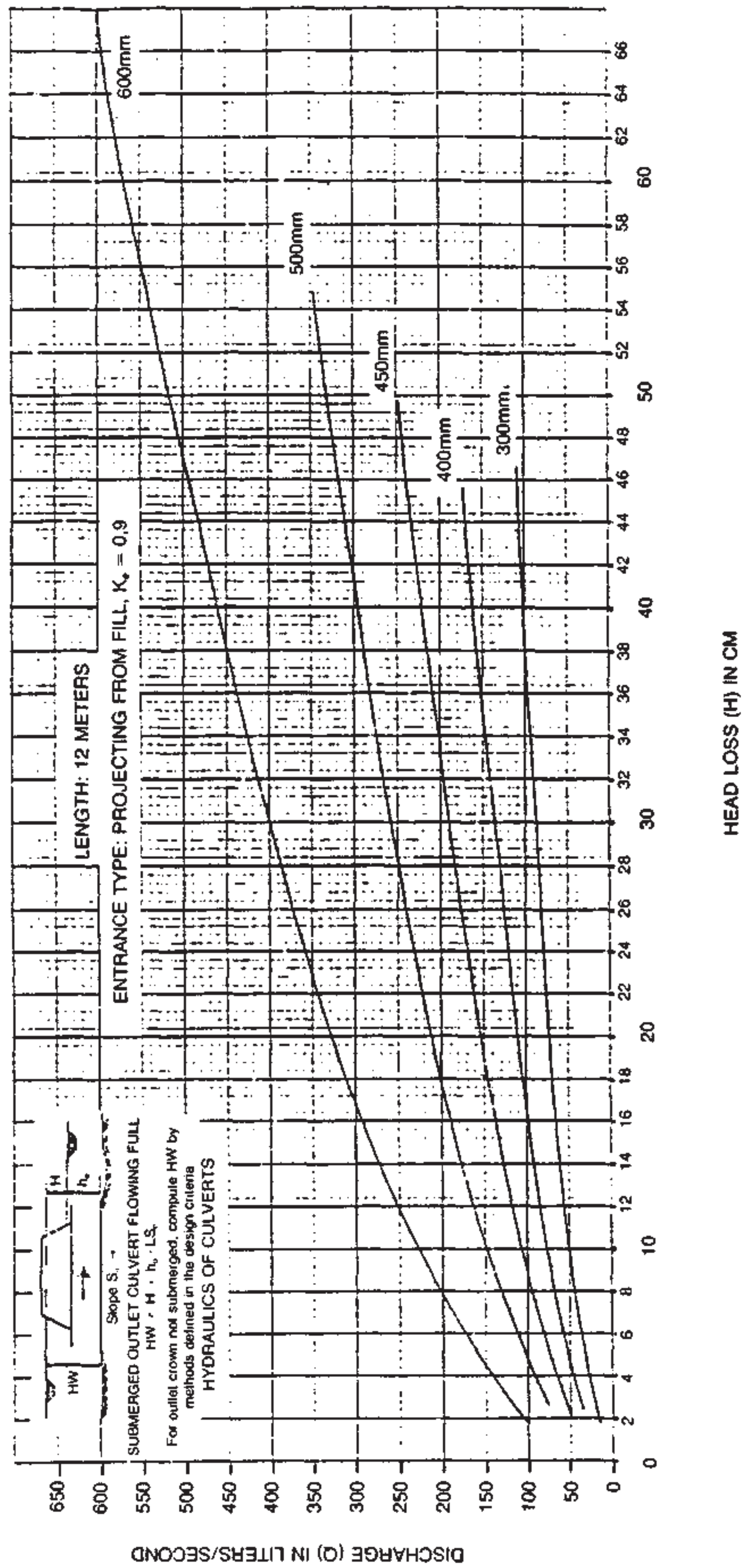


Fig 9.21 Head loss (H) in cm vs discharge (Q) in liters/second for Big 'O' heavy duty pipes

FLOWING FULL ~ OUTLET CONTROL


AD ASTRA PER ASPERA
Kansas
Department of Transportation
4458