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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

FLOW RESISTANCE COEFFICIENTS OF THREE SIZES OF CAST-IN-PLACE CONCRETE PIPE

Report No. Hyd-533

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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ABSTRACT

Hydraulic resistance coefficients were determined from head loss measurements made in 48-, 42-, and 36-inch-diameter cast-in-place concrete pipe installations. Data were obtained with the pipes flowing full at discharges less than the design values; from about 10 cubic feet per second to 25 cubic feet per second. Pipe test reaches varied from 1,240 to 3,895 feet. The hydraulic grade line was measured in 10-inch-diameter air vents used as piezometers; discharges were measured using a rectangular weir. Sufficient data were obtained to calculate flow resistance coefficients using the Darcy-Weisbach, Manning, and Scobey equations. The flow resistance coefficients for the 48- and 42-inch pipe and one reach of 36-inch pipe may contain residual losses produced by pipe entrance flow patterns, but the resistance coefficients for one reach of 36-inch pipe are believed to be representative of the values to be expected in long straight reaches.

DESCRIPTORS--Head losses/ Manning formula/ Darcy-Weisbach formula/ pipelines/ roughness coefficients/ pressure conduits/ concrete pipes

IDENTIFIERS--Cast-in-place pipe/ Madera Distribution System

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FLOW RESISTANCE COEFFICIENTS OF THREE SIZES OF CAST-IN-PLACE CONCRETE PIPE

SUMMARY

The purpose of the study discussed in this report was to determine the hydraulic flow resistance coefficients and physical characteristics of the interior surfaces of three sizes of cast-in-place concrete pipe. This study is part of a long-range program for evaluating the hydraulic characteristics of pipes installed in distribution systems and for determining the effect of aging on resistance coefficients. Three sizes of cast-in-place pipe, forming one continous pipeline, were tested and included a 3,895-foot section of 36-inch pipe, a 1,240-foot section of 42-inch pipe, and a 1,300-foot section of 48-inch pipe. Discharges were measured with a 6-foot rectangular weir installed at the inlet to the 48-inch pipe section. Head losses were measured with an electrical tape gage in 10-inch-diameter air vents used as piezometers.

The upstream air vents in each test section were located from 53 to 67 feet downstream from a gated check structure. There were three air vents and an access manhole in the 36-inch reach and two air vents in the 48- and 42-inch reaches. The upstream air vents, used as piezometers in the three test reaches, may be located in a region downstream from the pipe entrance where constant pressure gradients have not been established. Head losses in the 48- and 42-inch pipes and in the upstream reach of the 36-inch pipe may contain residual losses caused by entrance conditions and, the computed resistance coefficients may be applicable only to pipe sections and structures of similar configuration and length. However, the resistance coefficients computed for the 36-inch pipe using the two downstream air vents as piezometers should be indicative of the resistance coefficients for straight reaches of pipe with constant pressure gradients. Because of the short test reaches and the proximity of the upstream pipe vents to the inlets, the results of this test series are not conclusive. However, the value of these data will be considerably increased by repeating the test series at intervals to determine the effect of aging and by continuing the program on other distribution systems constructed of precast and cast-in-place pipe.

ACKNOWLEDGMENT

The test series described in this report was satisfactorily completed with the excellent cooperation of personnel from the Los Banos Project and Madera Irrigation District Offices.

INTRODUCTION

There is a dearth of information on the hydraulic roughness of cast-in-place concrete pipe. Flow resistance coefficients may be materially affected by possible variations in pipe size or shape, surface irregularities, or other factors, plus the unknown effects of aging. Because of these uncertainties, measurements on installed pipe of various ages are being carried out and should provide a greater fund of data for future planning.

The Madera Distribution System of the Central Valley Project, the first installation of cast-in-place concrete pipe made under Bureau specifications, afforded an opportunity to determine flow resistance coefficients and physical characteristics of three sizes of pipe which had been in use for a part of two irrigation seasons. The measurements completed in October 1963 are the beginning of a test series designed to provide some of the needed information on flow resistance coefficients of cast-in-place pipe.

GENERAL INFORMATION

Flow resistance coefficient tests were performed on cast-in-place concrete pipe now in service as part of Lateral 6.2-18.4 of the Madera Distribution System Extension, Part 2, Central Valley Project, Figure 1. The lateral consists of approximately 3 miles of earth-lined, open canal and 6 miles of low-head cast-in-place concrete pipe of 54-, 48-, 42-, 36-, and 30-inch inside diameters. All sections of pipe were constructed by a continuous forming process. The bottom of the trench was used as the outside form for approximately the bottom one-half of the pipe. The inside form consisted of a collapsible thin steel cylinder approximately 4.0 feet long with a circular reinforcing stud at each end. Consolidation of the concrete was accomplished by oscillating fingers operating within the concrete mass.

This lateral was completed under Bureau of Reclamation Specifications No. DC-5606 in March 1962, and was put in service in June 1962. The pipe system is designed to run full for all discharges and has either a gated check, an access shaft, or an air vent at approximately 1/4-mile intervals. The pipe can be entered for inspection through either the access shafts or the gated check structures. A typical gated check structure is shown in Figure 2, and a pipe vent and gated check are shown in Figure 3. All air vents are 10-inch-diameter metal pipe offset from the main conduit and extending from 5 to 8 feet above the ground surface, Figure 3.

DESCRIPTION OF TEST SYSTEM

Test Reaches

Three reaches of pipe were available for head loss measurements: 1,300 feet of 48-inch pipe from Station 254+00 to Station 267+00; 1,240 feet of 42-inch pipe from Station 280+60 to Station 293+00; and 3,895 feet of 36-inch pipe from Station 334+05 to Station 373+00. The reach of 30-inch pipe could not be tested as planned because the water to be used in the tests could not be disposed of elsewhere in the distribution system. Each test reach consisted of straight, uninterrupted pipe of the same diameter with no turnouts. Pipe vents were located at both ends of each test reach and were used as piezometers in determining head loss. The longer 36-inch reach had an additional air vent and an access shaft in the test section.

Pipe Inspection

A visual inspection was made of the flow surfaces of the entire test reach of the 48- and 42-inch pipes. The lower end of the 36-inch test reach was full of water and could not be drained; consequently, only 300 feet of this section was inspected. During the inspection, pipe diameters were measured with calipers at three locations in each test reach, Table 1. In the 48- and 42-inch pipe, diameters were measured near the upstream and downstream vents and near the midpoint of the test reach. At each location, four diameters were measured; horizontal, vertical, and two at 45°. In the 36-inch pipe, diameters were measured at three locations chosen at random in the upstream portion of the reach. These diameters were considered to be representative of the test section. The vent openings were examined in all the pipe reaches except the downstream reach of the 36-inch pipe. These irregular openings were, in general, about 12 inches in diameter with small amounts of mortar projecting into the flow, Figure 4.

General appearance of the inside surfaces of the pipe was good. The pipe was cast in sections about 4 feet long, leaving a transverse joint at the end of each form. Offsets at these joints are less than one-fourth inch and always away from the flow, Figures 4 and 5. The offsets are not uniform around the circumference and are generally larger in the upper half of the pipe. Some transverse joints have no appreciable offset, and the larger offsets and irregularities had been smoothed with mortar, Figure 5. Small longitudinal joints occur at the junction of the lower and upper halves of the forms. A thin layer of brown slime covered the upper 150° segment of the pipe, but was not thick enough to mask or cover the actual surface texture of the concrete. The pipe sagged in some sections with water standing as much as 6 inches deep. The invert contained a few small gravel deposits in these low spots.

At the downstream end of the 42-inch test section, a small amount of concrete had apparently fallen into the pipe during construction of the air vent, forming a mound on the invert directly beneath the vent which could not be removed by hand. The mound had a well defined geometry which could be measured. An area reduction, amounting to about 1.8 percent, was computed and used to adjust the velocity in the friction factor calculation.

MEASUREMENT AND CALCULATION PROCEDURES

Discharge Measurements

A 6-foot, fully contracted, rectangular weir was used as the water-measuring device for these tests, Figure 6. The wier was installed at the upstream end of the transition structure for the road crossing at Station 173+80. A 1-inch plywood bulkhead on a 2- by 4-inch wood frame was braced against the concrete inlet structure, Figures 6 and 7. Before backfilling, a plastic sheet seal was attached to the bulkhead with an asphalt joint sealer and was laid in a 1-foot-deep trench in front of the weir. No leakage past the bulkhead was apparent during the tests.

A 1/8-inch-thick brass plate 3 inches high with a machined sharp edge was used for the weir blade. The horizontal crest length of the installed weir blade was 6.004 feet; the vertical blades were 2.0 feet in length. The crest of the weir was 1.5 feet above the bottom of the weir pool. Ventilation of the nappe was complete throughout the full range of flows, Figures 7 and 8. Head on the weir was measured with a hook gage operating in a transparent plastic stilling well mounted on a 2- by 8-inch redwood post securely embedded in the weir pool 7.5 feet upstream of the weir blade, Figure 6. The inlet to the stilling well was connected with a 3/8-inch flexible plastic tube to a perforated metal can placed on the bottom of the canal in a region of low velocity. Using this equipment and procedure, any velocity effects on the head measurement were minimized. The dimensions of the weir pool for this installation were not standard as outlined in the Water Measurement Manual.1/ However, the depth and water surface widths were measured for various discharges and the average

1/Water Measurement Manual, U.S. Department of the Interior, Bureau of Reclamation, First Edition, May 1953.

velocity of approach was computed. For the maximum discharge of 24.9 cubic feet per second, the velocity of approach was 0.68 feet per second as compared to a velocity of 0.59 feet per second in a standard weir box for the same discharge. This difference in velocity of 0.09 foot per second results in an increase in velocity head of 0.002 foot or an increase in discharge of 0.08 cubic foot per second. The increase in discharge amounts to only 0.3 percent and the discharge was, therefore, not modified to account for the increased velocity of approach. An enameled staff gage mounted on the post served as a quick reference to the head on the weir and as a check on the hook gage measurements. Computed discharges for the heads measured during the tests are shown in Table 2.

Head Loss Measurements

Discharges were regulated upstream from the weir, at the turnout from Lateral 6.2, by district personnel. For each discharge measured at the weir, the gate in the gated check structure, Figure 2, at the end of each test reach was adjusted so that all pipes were flowing full and water surfaces were visible in the offset pipe vents. Flows were discharged through the check structure either through the gate at the bottom of the structure or over the top of the gate head wall, see Longitudinal Section, For Sloping Connection, h_2, Figure 2. After a change in discharge at the turnout to the test lateral, the system was allowed to stabilize before any head loss measurements were taken. Periodic head measurements at the weir were taken during each test to determine whether or not there were changes or fluctuations in the discharge. The maximum change during any test series was 0.3 cubic foot per second.

Distances from the top of the pipe vents to the water surface were measured with an electrical tape gage, Figure 8B. A steel tape with a 1-inch-diameter brass plumb bob was used as the water surface contact of the electrical circuit. A lead-weighted ground (electrical) line was lowered into the water in the pipe vent to complete the circuit through a milliammeter used to indicate the contact of the tape point and water surface. A small wooden spirit level was used to transfer the surveyed elevation on the rim of the vent to the point inside the pipe at which the tape measurement was taken. Due to the fluctuations of the water surface in the pipe vents, it was necessary to take a number of random measurements to obtain an average. The number of measurements taken at each vent varied from 10 to 30 depending on the amount of fluctuation of the water surface, Tables 3, 4, and 5.

Lateral 6.2 wasteway, crossing Lateral 6.2-18.4 at the lower end of the 36-inch reach, was used to convey the test discharge to the San Joaquin River. Flows of approximately 10, 17, and 23 cubic feet per second were used for tests in the 36-inch pipe designed for a discharge of 20 cubic feet per second. By diverting water from the lateral through two farm turnouts in the lower end of the 42-inch pipe, it was possible to obtain test discharges of 10, 17, 23, and 25 cubic feet per second in the 48- and 42-inch pipes. The design discharge of 35 cubic feet per second in the 48-inch pipe and 30 cubic feet per second in the 42-inch pipe could not be obtained because of a lack of facilities to dispose of the excess water.

Method of Calculation

Using the surveyed difference in elevation between the tops of pipe vents at the ends of each test section and the average distances, d_1, d_2, or d_3 from the tops of the vents to the water surfaces, the head loss for each discharge was calculated. The average diameter was used in the calculation of head loss for the 48- and 36-inch pipe test sections. In the 42-inch pipe, the area reduction at the downstream vent caused by a mound of concrete made it necessary to include the velocity head difference, $\frac{V_2^2 - V_1^2}{2g}$, in the calculation of head loss, Table 6. The Darcy-Weisbach friction factor "f" was computed from the formula:

$$h_L = f \frac{L}{D} \frac{V^2}{2g} \text{ or } f = \frac{2gh_L D}{LV^2}$$

where:

g = 32.2 ft/sec^2
D = average pipe diameter-feet
L = length of test section-feet
V = average velocity in pipe-ft/sec
h_L = head loss-feet

Manning's "n" was computed from the formula:

$$V = \frac{1.486\, R^{2/3}\, S^{1/2}}{n} \text{ or } n = \frac{1.486\, R^{2/3}\, S^{1/2}}{V}$$

where:

R = hydraulic radius
S = friction slope = $\frac{h_L}{L}$

Combining the equations for "f" and "n":

$$n = 0.0734\, D^{1/6} f^{1/2}$$

The Scobey pipe coefficient for concrete pipes was computed the formula:2/

$$V = C_s H_f^{0.5} d_i^{0.625} \text{ or } C_s = \frac{V}{H_f^{0.5} d_i^{0.625}}$$

where:

H_f = friction loss per 1,000 feet

d_i = pipe diameter in inches

DISCUSSION OF RESULTS

A summary of computed values of the Darcy-Weisbach "f", Manning's "n", and Scobey resistance coefficient "C_s" for the three sizes of pipe is shown in Table A, below. Values for the 36-inch pipe were computed from the water surface elevations in the pipe sections between the three available air vents. Computations for friction factors and roughness coefficients are included in Table 6. Figure 9 shows the plot of "f" and "n" versus Reynold's number for the range of discharges.

Head losses in a pipe reach are caused essentially by two phenomena in the pipe; namely, by the development of the boundary layer in the region of flow establishment near the inlet and by the normal friction occurring in the region of constant pressure gradient. Losses per unit length in the upstream or developing segment are larger than for an equivalent length in fully established flow. The losses in the inlet segment over and above those losses in an equivalent length of pipe in fully established flow are sometimes referred to as "residual" losses and are attributable to entrance losses and boundary layer development. In this pipe distribution system the entrance losses may be additionally increased by the water flowing through the gate and over the gate head wall of the check structures, Figure 2. Head differentials measured in the region of boundary layer development will indicate higher head losses and will result in higher computed resistance coefficients.

Extensive data on friction factors in concrete pipe indicate that for 36-inch cast concrete pipe, a constant pressure gradient is established at a point about 95 to 100 feet from a bellmouth entrance.3/

2/King, H. W., "Handbook of Hydraulics," Third Edition, McGraw Hill, 1939.

3/Straub, L. G., Bowers, C. E., and Pilch, Meir, "Resistance to Flow in Two Types of Concrete Pipe," Technical Paper No. 22, Series B, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, Minnesota, December 1960, page 21.

Table A

SUMMARY OF RESISTANCE COEFFICIENT TESTS
CAST-IN-PLACE CONCRETE PIPE
MADERA DISTRIBUTION SYSTEM

Discharge (cfs)	Reynold's number, $N_R \times 10^{-5}$	Darcy-Weisbach f	Manning's "n"	Scobey coefficient C_s
		48-inch pipe		
10.11	2.75	0.0643	0.0235	0.178
16.05	4.36	0.0244	0.0144	0.288
22.51	6.10	0.0187	0.0126	0.330
22.81	6.19	0.0170	0.0120	0.346
24.86	6.75	0.0150	0.0114	0.368
		42-inch pipe		
10.40	3.23	0.0452	0.0193	0.215
16.07	4.98	0.0282	0.0152	0.273
22.66	7.03	0.0229	0.0137	0.303
24.88	7.72	0.0212	0.0132	0.315
		36-inch pipe (Vents 1 and 2)		
10.09	3.63	0.0222	0.0122	0.314
17.40	6.26	0.0153	0.0102	0.378
22.81	8.21	0.0167	0.0107	0.361
		36-inch pipe (Vents 2 and 3)		
10.09	3.63	0.0200	0.0116	0.330
17.40	6.26	0.0129	0.0093	0.413
22.81	8.21	0.0160	0.0104	0.369

A somewhat longer distance would be required for larger diameter pipes.4/

Resistance coefficients for the 36-inch pipe were computed for the upstream reach between Vents 1 and 2 and for the downstream reach between Vents 2 and 3, Table A. A comparison of the results shows that the "f" values for the upstream reach are about 11 percent higher than those for the downstream reach and because Manning's "n" varies as the square root of "f", the corresponding "n" values are about 5 percent higher. Since the upstream air vent (Number 1) is only 53 feet downstream from the inlet and is, therefore, in the region of flow development, head loss measurements in the 36-inch pipe using Vents 1 and 2 probably contain residual losses.

The upstream air vents used as piezometers in the 42- and 48-inch pipes were located 66 and 67 feet, respectively, downstream from the gate in the check structure. Therefore, the measured head losses using these air vents as piezometers may include some residual losses and may not be indicative of the friction loss in an equivalent length of pipe with a constant pressure gradient.

The air vents used as piezometers were of large diameter compared to the usual piezometer installations and some of the openings were not smoothly formed, Figure 4. It is, therefore, possible that the static heads indicated by the water surface elevations in the air vents were not the true pressure heads. However, the relative difference in water surface elevations using piezometers with openings of the same size and shape should be a reliable indication of the head loss between vents.

The results shown in Table A are based on pipe vent elevations determined from a precise survey made on each test reach. Head loss measurements on the 48- and 42-inch test reaches may contain some residual losses from the entrance, and the test reaches were quite short. The friction factors and Manning's "n" shown on Figure 9 and in Table A, for the 36-inch pipe between Vents 2 and 3 were computed from head losses which were not affected by residual losses and with a test reach approximately twice as long as for the other pipe sizes. Friction factors computed for this section of 36-inch pipe should correspond to those for flow with a constant pressure gradient. The 48-, 42-inch, and the section of 36-inch pipe between Vents 1 and 2 show larger resistance coefficients than the section of 36-inch between Vents 2 and 3 possibly because of residual losses included in the head loss measurements. The general slope of the

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4/Keulegan, Garbis H., Research Report 6-B, Highway Research Board, December 1948.

curves is steeper than the classical Von Karman-Nikuradse resistance coefficient curve for smooth pipes, Figure 9, and is predominantly influenced by the high resistance coefficients found in each pipe for the lowest Reynold's numbers. Since high resistance coefficients for all pipes were found for the test discharge of about 10 cubic feet per second, it is possible that an error in discharge measurement occurred. However, no discrepancies could be found in the data or discharge calculations.

CONCLUSIONS

1. The upstream air vents used as piezometers in the three test reaches may be located in the region of boundary layer development; this may have resulted in higher head losses and in higher resistance coefficients than would occur in long reaches of similar pipe located well downstream from an entrance structure.

2. The resistance coefficients for the lower Reynold's numbers, Table A and Figure 9, are larger than expected. However, a study of the data and the conditions accompanying the measurements made at the 10-cubic-foot-per-second discharge failed to disclose any discrepancy.

3. It is believed that head losses measured in the 48- and 42-inch pipe and in the upstream reach of the 36-inch pipe may contain residual losses resulting from entrance structure flow patterns but should be representative of pipe installations of similar configuration. Resistance coefficients computed for the 36-inch pipe, using the two downstream air vents as piezometers, should be representative of flow resistance coefficients for this pipe flowing with a constant pressure gradient.

4. The results of this study will be considerably more valuable if tests are repeated as the pipe ages and the program is continued on other distribution systems constructed of precast and cast-in-place pipe.

5. Piezometers should be included in future pipe installations to provide better facilities for the measurement of pressure head.

Table 1

MEASURED PIPE DIAMETERS

	Horizontal	Vertical	45°	45°	Average
48-inch pipe					
Section 1	3.960	3.932	4.014	4.024	3.983
Section 2	4.040	4.063	4.074	4.024	4.050
Section 3	3.967	4.008	4.008	4.000	3.996
				Average	4.010
42-inch pipe					
Section 1	3.496	3.517	3.520	3.493	3.507
Section 2	3.486	3.511	3.518	3.507	3.506
Section 3	3.521	3.531	3.500	3.485	3.509
				Average	3.507
36-inch pipe					
Section 1	2.990	3.022	3.016	3.017	3.011
Section 2	2.990	3.093	3.103	3.033	3.055
Section 3	2.982	3.009	3.008	3.004	3.001
				Average	3.022

Flow Resistance Coefficients Cast-in-place Pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT

Table 2

COMPUTED WEIR DISCHARGES

$$Q = 3.33\ (L - 0.2H)\ H^{3/2}$$

L = 6.004 feet

Head H	(L - 0.2H)	$H^{3/2}$	Q
0.643	5.875	0.516	10.09
0.644	5.875	0.517	10.11
0.656	5.873	0.532	10.40
0.881	5.828	0.827	16.05
0.882	5.828	0.828	16.07
0.931	5.818	0.898	17.40
1.110	5.782	1.169	22.51
1.115	5.781	1.177	22.66
1.120	5.780	1.185	22.81
1.188	5.766	1.295	24.86
1.189	5.766	1.296	24.88

Flow Resistance Coefficients Cast-in-place Pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT

Table 3

TAPE READINGS IN 48-INCH PIPE VENTS
Elevation Pipe Vent 1 = 244.240
Elevation Pipe Vent 2 = 242.570
Length of reach, Station 254+00 to Station 267+00 = 1,300 feet
d = Distance from top of pipe vent to water surface

Date	Weir head feet	Discharge cfs	d_1 feet			d_2 feet		
10-24-63			6.926		6.932	5.462		5.466
			6.921		6.920	5.463		5.460
	0.881	16.05	6.912		6.924	5.453		5.464
			6.919		6.937	5.450		5.450
			6.928		6.916	5.440		5.445
		Total		69.235			54.533	
		Average		6.924			5.453	
10-24-63			8.048		8.058	6.687		6.687
			8.062		8.059	6.695		6.686
			8.065		8.062	6.688		6.695
			8.056		8.052	6.694		6.686
	1.110	22.51	8.053		8.058	6.697		6.694
			8.065		8.063	6.694		6.668
			8.060		8.062	6.667		6.699
			8.067		8.068	6.701		6.698
			8.065		8.066	6.695		6.692
			8.070		8.070	6.697		6.700
		Total		161.229			133.820	
		Average		8.062			6.691	
10-24-63			8.100		8.090	6.698		6.697
			8.076		8.089	6.702		6.694
			8.100		8.089	6.698		6.690
			8.088		8.091	6.697		6.701
	1.120	22.81	8.096		8.096	6.698		6.692
			8.088		8.083	6.698		6.694
			8.087		8.100	6.695		6.695
			8.089		8.081	6.703		6.698
			8.093		8.096	6.713		6.704
			8.087		8.089	6.699		6.710
		Total		161.808			133.976	
		Average		8.090			6.699	
10-25-63			8.634		8.643	7.174		7.177
			8.639		8.643	7.175		7.177
			8.642		8.642	7.177		7.176
			8.642		8.647	7.184		7.185
			8.650		8.657	7.196		7.193
	0.644	10.11	8.654		8.653	7.198		7.198
			8.655		8.656	7.198		7.191
			8.659		8.655	7.188		7.190
			8.652		8.650	7.192		7.185
			8.650		8.656	7.194		7.198
		Total		172.979			143.746	
		Average		8.649			7.187	

Table 3--Continued

Date	Weir head feet	Discharge cfs	d1 ft			d2 ft		
10-25-63			8.060		8.062	6.686		6.679
			8.044		8.059	6.671		6.674
			8.064		8.058	6.671		6.668
			8.063		8.069	6.663		6.664
			8.061		8.061	6.668		6.672
			8.063		8.078	6.674		6.672
	1.188	24.86	8.073		8.075	6.680		6.685
			8.070		8.076	6.682		7.001
			8.085		8.060	6.694		6.689
			8.075		8.057	6.688		6.685
			8.062		8.073	6.680		6.682
			8.073		8.073	6.680		6.688
			8.069		8.062	6.689		6.696
			8.077		8.075	6.686		6.697
			8.076		8.071	6.690		6.689
		Total		242.024			200.743	
		Average		8.067			6.691	

Table 4

TAPE READINGS IN 42-INCH PIPE VENTS
Elevation Pipe Vent 1 = 240.790
Elevation Pipe Vent 2 = 239.645
Length of reach, Station 280+60 to Station 293+00 = 1,240 feet
d = Distance from top of pipe vent to water surface

Date	Weir head feet	Discharge cfs	d_1 feet			d_2 feet		
10-24-63			8.963		8.966	8.252		8.247
			8.969		8.950	8.250		8.240
	0.882	16.07	8.976		8.957	8.245		8.252
			8.952		8.964	8.248		8.236
			8.945		8.970	8.251		8.238
		Total		89.612			82.459	
		Average		8.961			8.246	
10-24-63			8.158		8.150	7.715		7.719
			8.166		8.186	7.710		7.722
			8.157		8.176	7.722		7.728
			8.141		8.170	7.726		7.722
	1.115	22.66	8.169		8.165	7.725		7.722
			8.157		8.187	7.727		7.719
			8.167		8.184	7.718		7.730
			8.189		8.183	7.728		7.718
			8.174		8.190	7.724		7.727
			8.183		8.200	7.718		7.724
		Total		163.452			154.444	
		Average		8.173			7.722	
10-25-63			9.475		9.472	8.611		8.626
			9.471		9.480	8.608		8.621
			9.498		9.502	8.628		8.628
			9.460		9.483	8.627		8.624
			9.485		9.484	8.628		8.632
			9.486		9.475	8.638		8.634
			9.487		9.487	8.628		8.630
			9.480		9.481	8.630		8.618
	0.656	10.40	9.474		9.488	8.620		8.623
			9.472		9.484	8.620		8.619
			9.408		9.477	8.622		8.629
			9.480		9.484	8.626		8.633
			9.491		9.498	8.624		8.638
			9.480		9.468	8.636		8.623
			9.466		9.490	8.625		8.620
		Total		284.446			258.769	
		Average		9.482			8.626	

Table 4--Continued

Date	Weir head feet	Discharge cfs	d_1 feet			d_2 feet		
10-25-63			7.335		7.321	6.968		6.970
			7.349		7.361	6.984		6.990
			7.350		7.348	6.967		6.982
			7.333		7.342	6.982		6.985
	1.189	24.88	7.349		7.339	6.995		6.997
			7.339		7.355	6.991		6.960
			7.357		7.358	6.985		6.984
			7.344		7.353	6.971		6.984
			7.358		7.342	6.983		6.982
			7.357		7.355	6.970		6.956
			7.339		7.364	7.001		7.000
			7.367		7.376	6.985		6.990
			7.358		7.350	6.979		6.999
			7.366		7.352	7.000		6.978
			7.352		7.335	6.983		6.942
		Total		220.504			209.463	
		Average		7.350			6.982	

Table 5

TAPE READINGS IN 36-INCH PIPE VENTS
Elevation Pipe Vent 1 = 234.697
Elevation Pipe Vent 2 = 233.867
Elevation Pipe Vent 3 = 228.740
Length of reach, Station 334+05 to Station 347+00 to Station 373+00 = 3,895 feet
d = Distance from top of pipe vent to water surface

Date	Weir head feet	Discharge cfs		d_1 feet	d_2 feet	d_3 feet
10-24-63				8.111	7.880	3.750
				8.080	7.868	3.758
				8.07	7.870	3.739
				8.06	7.845	3.740
	0.931	17.40		8.07	7.840	3.718
				8.02	7.830	3.711
				8.08	7.784	3.720
				8.07	7.830	3.699
				8.05	7.770	3.692
			Total	80.671	78.365	37.245
			Average	8.067	7.837	3.725
10-24-63				4.900	5.177	2.206
				4.842	5.178	2.214
				4.828	5.154	2.201
				4.811	5.179	2.221
				4.859	5.215	2.248
				4.888	5.164	2.230
				4.893	5.162	2.228
				4.863	5.178	2.226
	1.120	22.81		4.876	5.194	2.214
				4.871	5.174	2.200
				4.871	5.168	2.202
				4.894	5.158	2.209
				4.901	5.157	2.238
				4.945	5.185	2.200
				4.898	5.167	2.200
				4.882	5.178	2.230
				4.859	5.194	2.212
				4.868	5.160	2.235
				4.901	5.171	2.202
				4.868	5.190	2.213
			Total	97.518	103.502	44.329
			Average	4.876	5.175	2.216

Table 5--Continued

Date	Weir head feet	Discharge cfs		d1 feet	d2 feet	d3 feet
10-25-63				8.985	8.515	3.910
				8.973	8.488	3.918
				9.034	8.490	3.912
				9.077	8.488	3.910
				9.071	8.499	3.917
				9.072	8.494	3.922
				9.063	8.505	3.906
				9.042	8.515	3.905
				9.078	8.525	3.938
				9.048	8.530	3.900
				9.047	8.532	3.942
				9.056	8.520	3.919
				9.044	8.524	3.927
				9.047	8.548	3.927
	0.643	10.09		9.062	8.544	3.914
				9.091	8.526	3.919
				9.084	8.520	3.945
				9.069	8.502	3.938
				9.100	8.533	3.923
				9.098	8.554	3.910
				9.037	8.515	
				9.057	8.506	
				9.088	8.522	
				9.056	8.492	
				9.062	8.520	
				9.060	8.527	
				9.017	8.535	
				9.031	8.514	
					8.540	
					8.531	
			Total	253.549	255.554	78.402
			Average	9.055	8.518	3.920

Table 6

RESISTANCE COEFFICIENT CALCULATIONS

48-inch Pipe

h_L = Elevation 1 -Elevation 2 $-d_1 + d_2$

Length = 1,300 feet

$= 244.240 - 242.570 - (d_1 - d_2)$

$= 1.670 - (d_1 - d_2)$

Area = 12.63 ft^2

Average diameter (D) = 4.010

$$f = \frac{2gh_LD}{LV^2} \quad \frac{64.32h_LD}{LV^2}$$

Q	V	d_1	d_2	h_L	f	n	C_s
10.11	0.801	8.649	7.187	0.208	0.0643	0.0235	0.178
16.05	1.271	6.924	5.453	0.199	0.0244	0.0144	0.288
22.51	1.782	8.062	6.691	0.299	0.0187	0.0126	0.330
22.81	1.806	8.090	6.699	0.279	0.0170	0.0120	0.346
24.86	1.969	8.067	6.691	0.294	0.0150	0.0114	0.368

$$n = 0.0734\, D^{1/6} f^{1/2}$$

$$D^{1/6} = 1.261$$

C_s = Scobey coefficient for concrete pipes

$$C_s = \frac{V}{H_f^{0.5} d_i^{0.625}}$$

d_i = diameter in inches
H_f = friction loss per 1,000 feet
L = length in 1,000-foot increments

$$= \frac{VL^{0.5}}{h_L^{0.5} D^{0.625} (12)^{0.625}}$$

$$= \frac{0.2114\, VL}{h_L^{0.5} D^{0.625}}$$

$D^{0.625} = 2.384$

$L^{0.5} = 1.14$

$$= \frac{0.1011V}{h_L^{0.5}}$$

Table 6--Continued

42-inch Pipe

$$h_L = \text{Elevation 1} - \text{Elevation 2} - d_1 + d_2 - \left(\frac{V_2^2 - V_1^2}{2g}\right)$$

Length = 1,240 feet

$$= 240.790 - 239.645 - d_1 + d_2 - \left(\frac{V_2^2 - V_1^2}{2g}\right)$$

$Area_1 = 9.66$ $Area_2 = 9.50$ Average diameter (D) = 3.507

Q	V_1	V_2	d_1	d_2	h_L	f	n	C_s
10.40	1.077	1.095	9.482	8.626	0.288	0.0452	0.0193	0.215
16.07	1.663	1.691	8.961	8.246	0.429	0.0282	0.0152	0.273
22.66	2.346	2.385	8.173	7.722	0.691	0.0229	0.0137	0.303
24.88	2.576	2.619	7.350	6.982	0.773	0.0212	0.0132	0.315

$$n = 0.0734\, D^{1/6} f^{1/2}$$

$$D^{1/6} = 1.232$$

C_s = Scobey coefficient for concrete pipes

$$C_s = \frac{V_1}{H_f^{0.5} d_i^{0.625}}$$

d_i = diameter in inches
H_f = friction loss per 1,000 feet
L = length in 1,000-foot increments

$$= \frac{V_1 L^{0.5}}{h_L^{0.5} D^{0.625} (12)^{0.625}}$$

$$= \frac{0.2114\, V_1 L^{0.5}}{h_L^{0.5} D^{0.625}}$$

$D^{0.625} = 2.190$

$L^{0.5} = 1.113$

$$= \frac{0.1074\, V_1}{h_L^{0.5}}$$

Table 6--Continued

36-inch Pipe

$h_{L_{1-2}}$ = Elevation 1 -Elevation 2 $-d_1 + d_2$ Length$_{1-2}$ = 1,295 feet

$= 234.697 - 233.867 - d_1 + d_2$

$= 0.830 - d_1 + d_2$

$h_{L_{2-3}}$ = Elevation 2 -Elevation 3 $-d_2 + d_3$ Length$_{2-3}$ = 2,600 feet

$= 233.867 - 228.740 - d_2 + d_3$

$= 5.127 - d_2 + d_3$

Average diameter (D) = 3.022 Area = 7.17

Q	V	d_1	d_2	d_3	$h_{L_{1-2}}$	$h_{L_{2-3}}$	f_{1-2}	f_{2-3}	n_{1-2}	n_{2-3}	$C_{s_{1-2}}$	$C_{s_{2-3}}$
10.09	1.407	9.055	8.518	3.920	0.293	0.529	0.0222	0.0200	0.0122	0.0116	0.314	0.330
17.40	2.425	8.067	7.837	3.725	0.600	1.015	0.0153	0.0129	0.0102	0.0093	0.378	0.413
22.81	3.180	4.876	5.175	2.216	1.129	2.168	0.0167	0.0160	0.0107	0.0104	0.361	0.369

$$n = 0.0734\, D^{1/6} f^{1/2}$$

$$D^{1/6} = 1.117$$

C_s = Scobey coefficient for concrete pipes

$$C_s = \frac{V}{H_f^{0.5}\, d_i^{0.625}}$$

d_i = diameter in inches

H_f = friction loss per 1,000 feet

L = length in 1,000-foot increments

$$= \frac{VL^{0.5}}{h_L^{0.5} D^{0.625} (12)^{0.625}}$$

$$= \frac{0.2114\, VL^{0.5}}{h_L^{0.5} D^{0.625}}$$

$$C_{s_{1-2}} = \frac{0.1207V}{h_L^{0.5}}$$

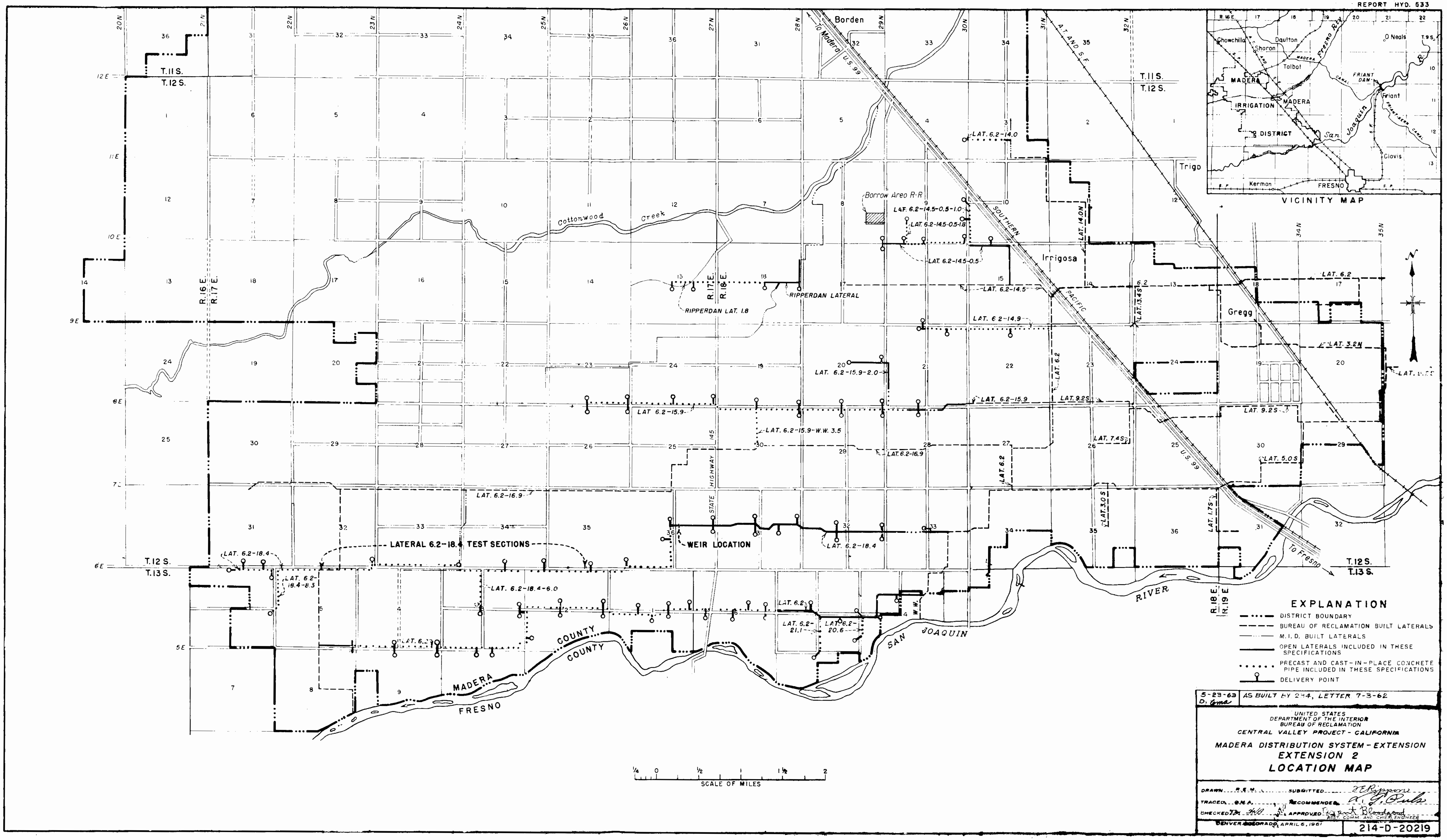
$$L_{1-2}^{0.5} = 1.14$$

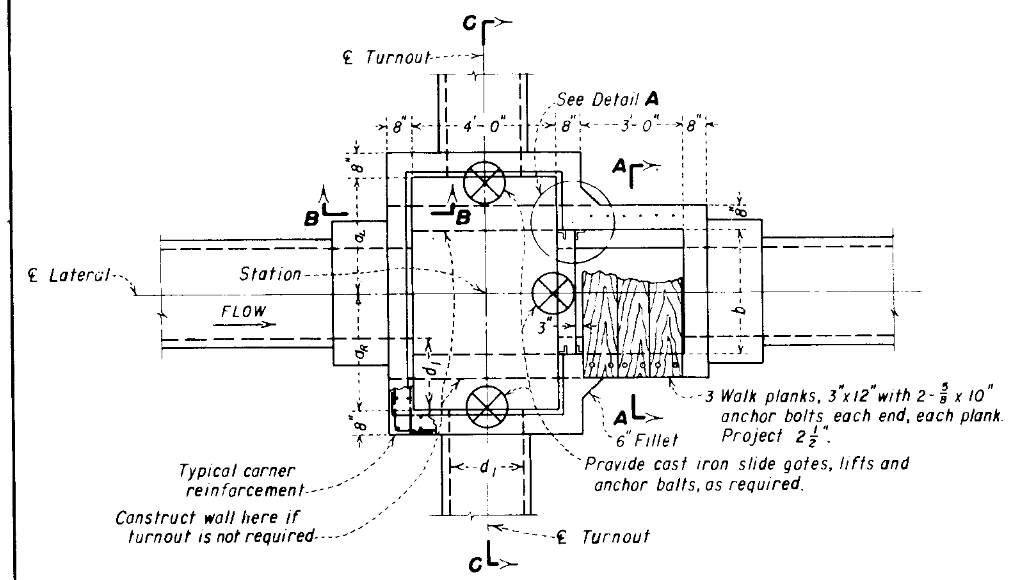
$$D^{0.625} = 1.996$$

$$C_{s_{2-3}} = \frac{0.1707V}{h_L^{0.5}}$$

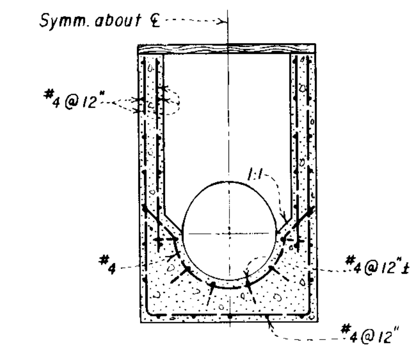
$$L_{2-3}^{0.5} = 1.612$$

FIGURE 1
REPORT HYD. 533

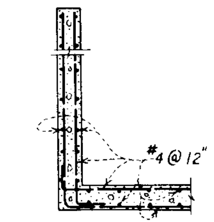




PLAN



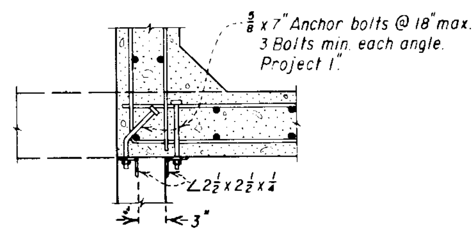
SECTION A-A



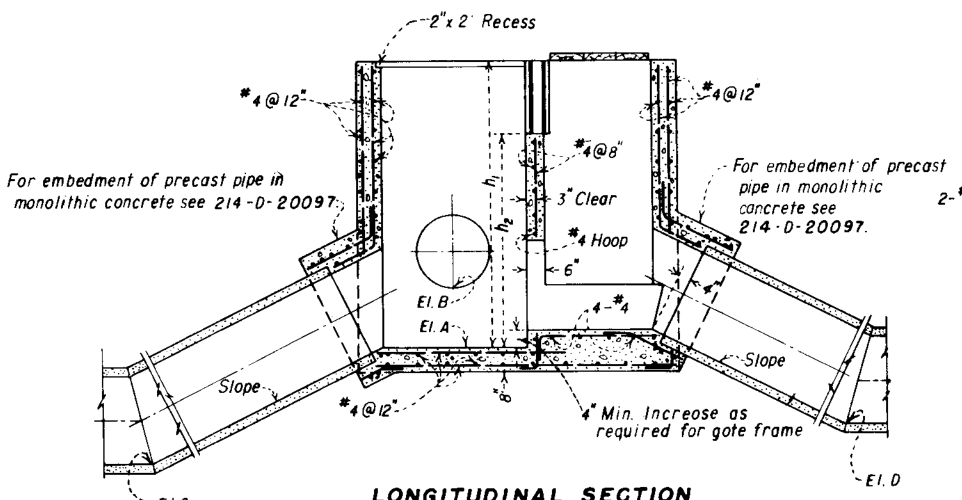
SECTION B-B

LATERAL	STATION	INLET PIPE		OUTLET PIPE		TURNOUT		ELEVATION			DIMENSION					GATE AHEAD		ESTIMATED QUANTITIES		REMARKS
		DIA. (IN.)	SLOPE	DIA. (IN.)	SLOPE	DIA. (IN.)	DIR.	A	B	C	a_L	a_R	b	h_1	h_2	HEAD AT ℄ (FT.)	FRAME HEIGHT (FT.)	CONCRETE (CU. YDS.)	REINF. STEEL (LBS.)	
	181+11.00	48	.00	48	-.00057	24	Rt.	235.50	238.55		2'-6"	4'-0"	5'-0"	11'-3"	8'-9"	6.9	10	10.6	1130	
do	226+41.63	48	-.00028	48	.00	24	Rt.	231.47	234.05		2'-6"	4'-0"	5'-0"	11'-3"	8'-9"	7.0	10	10.6	1130	See 214-D-20234
do	253+ .00	48	-.00044	48	-.00171	24	Rt.	229.22	230.55		2'-6"	4'-0"	5'-0"	11'-4"	8'-10"	7.0	10	10.6	1150	
do	279+88.00	48	-.00171	42 (1)	-.00063	24	Rt.	225.01	228.75		2'-6"	4'-0"	5'-0"	13'-6"	11'-0"	9.4	13	12.4	1320	
do	306+29.00	42	-.00360	42 (1)	-.00040	24	Rt.	220.04	223.05		2'-3"	3'-9"	4'-6"	15'-5"	13'-0"	11.4	15	14.2	1520	
do	320+26.58	42	.00	42 (1)	-.00085	30	Lt.	219.83	222.50		4'-3"	2'-3"	4'-6"	13'-8"	11'-5"	9.9	13	12.7	1360	
do	333+46.00			36												10.1	13			See 214-D-20246
do	386+13.00	36	.00	36	.00	24	Rt.	211.00	213.25		24"	3'-6"	4'-0"	15'-0"	12'-10"	11.5	15	13.1	1400	See 214-D-20234
do	425+95.53			30												10.6	14			See 214-D-20247
do	453+40.00	30	.00	30	.00	24	Lt.	203.93	206.05		3'-3"	21"	3'-6"	12'-2"	10'-0"	9.1	12	10.2	1100	

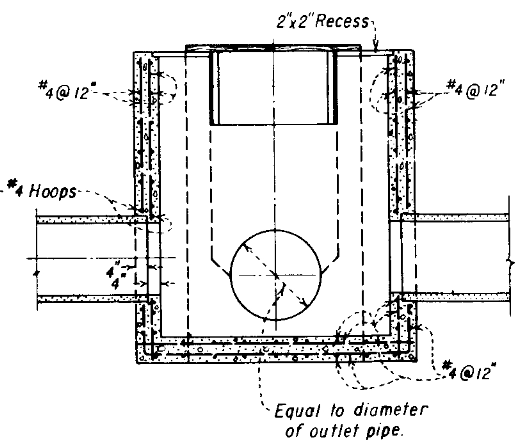
(1) 42" x 42" Cast-iron slide gate
(2) 60" x 60" " " " "
} All other gates to be circular



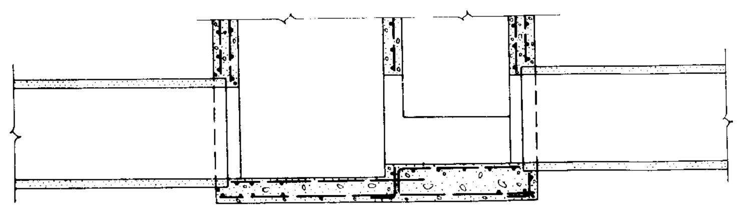
DETAIL A



LONGITUDINAL SECTION
FOR SLOPING CONNECTION



SECTION C-C



LONGITUDINAL SECTION
FOR STRAIGHT CONNECTION

NOTES

Unless otherwise shown, place reinforcement so that the clear distance between face of concrete and nearest reinforcement is 1 1/2 inches, except that where concrete is placed against earth or rock, the minimum clear distance shall be 2 inches.
Lap all bars 24 diameters at splices.
Monolithic concrete design based on a compressive strength of 3000 pounds per square inch at 28 days.
For details of turnout see 214-D-20220 thru 20224
A maximum of 20 feet of precast concrete pressure pipe (B25) shall be installed on each side of any structure occuring in a reach of cast-in-place pipe, and a rubber gasketed joint shall be provided at or within 18 inches of the structure.
Anchor bolts to have square heads, hex. nuts and cut washers.

REV. 234 P.M. — ... CHECK FROM STA. 226-56.00 TO 226+41.63 & FROM STA 181+.3 TO 181+11
REV. 234 — LOWERED ELEV. A ... 0.5' STA. 38 ... 13.00 AND 453+40.00
REV. 234 — MOVED GATED CHECK FROM STA. ... TO ... +13.0.
REV. 1-10-62 234 D.W. MOVED GATED CHECK TO 253+36.00 DELETED GATED CHECK AT 131+44.00

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CENTRAL VALLEY PROJECT-CALIFORNIA

MADERA DISTRIBUTION SYSTEM-EXTENSION 2

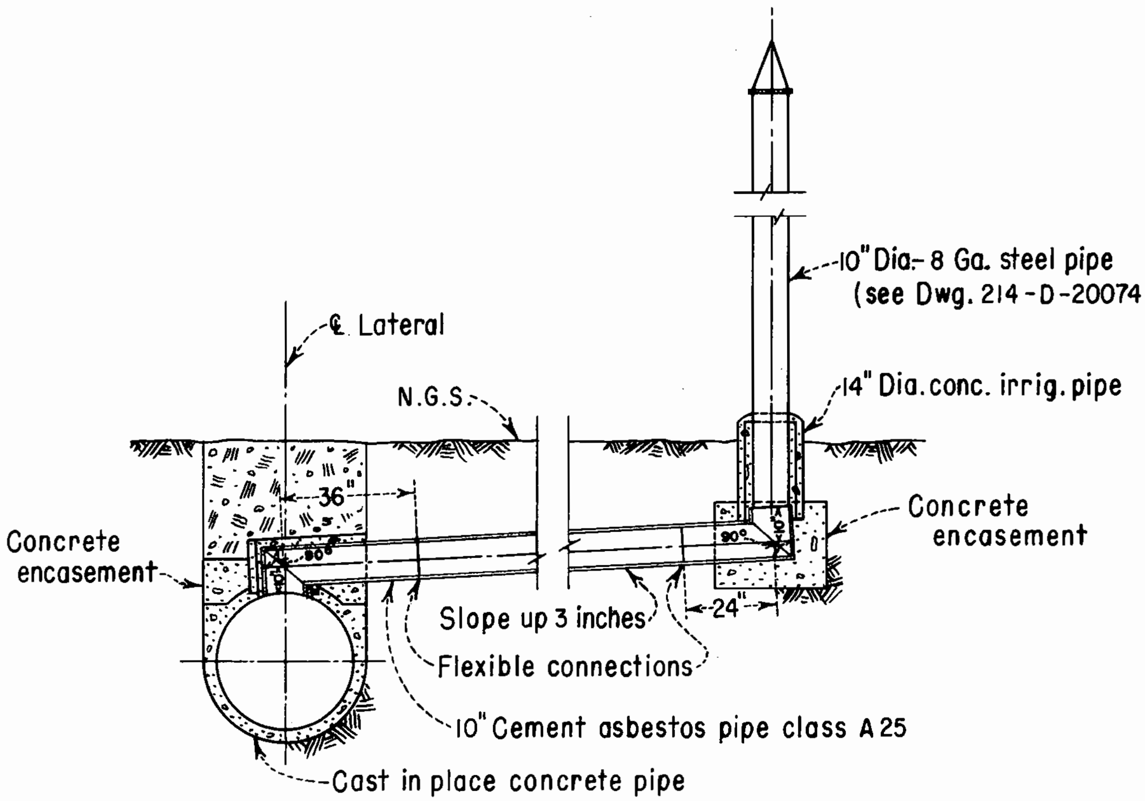
GATED CHECKS

DRAWN R.B.H. SUBMITTED W. J. Schneider
TRACED L.L.G. RECOMMENDED [signature]
CHECKED R.W.S. [signature] APPROVED [signature] CHIEF DESIGNING ENGINEER

DENVER, COLORADO, APRIL 6, 1961
SHEET 2 OF 3

214-D-20243

A. GATED CHECK STRUCTURE AND 10-INCH DIAMETER AIR VENT



B. OFFSET AIR VENT IN CAST-IN-PLACE CONCRETE PIPE

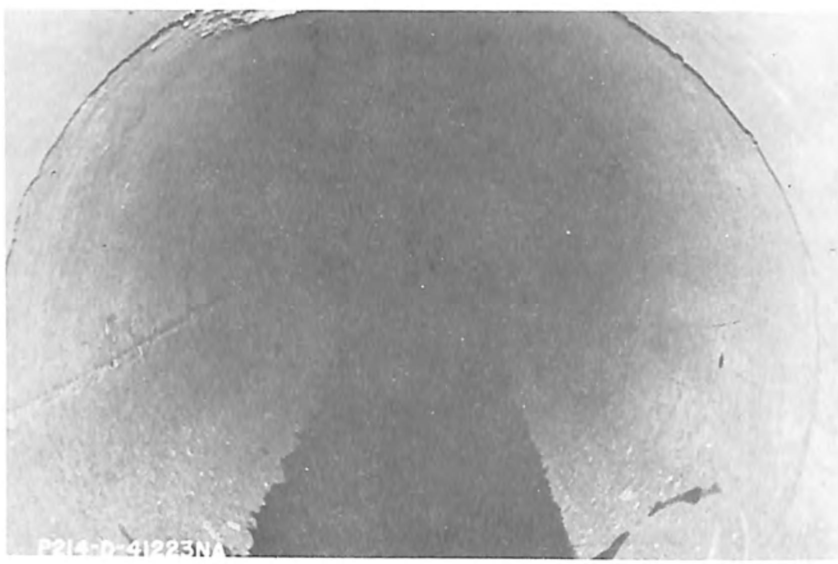
RESISTANCE COEFFICIENTS CAST-IN-PLACE PIPE

MADERA DISTRIBUTION SYSTEM-CENTRAL VALLEY PROJECT

TYPICAL GATED CHECK STRUCTURE AND PIPE VENT

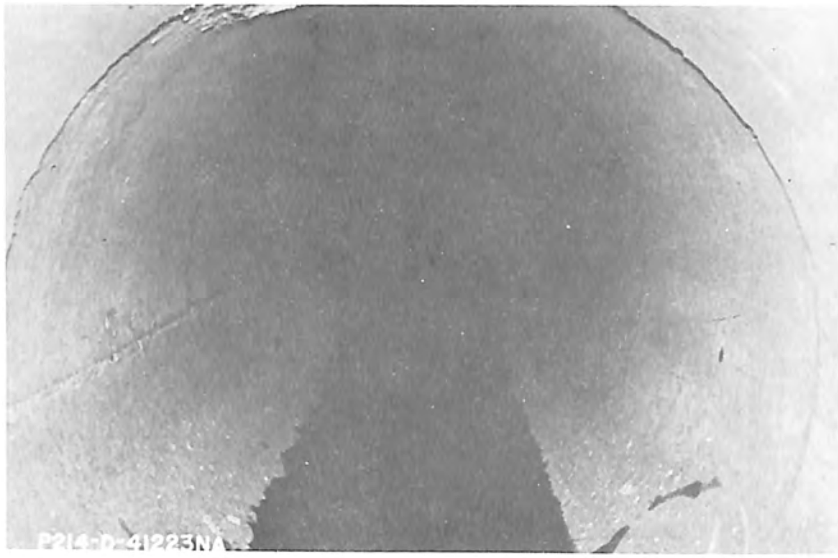
Figure 4
Report Hyd-533

A. Vent in crown (light area) of 42-inch cast-in-place pipe, showing slight mortar protrusions, Station 293+00.

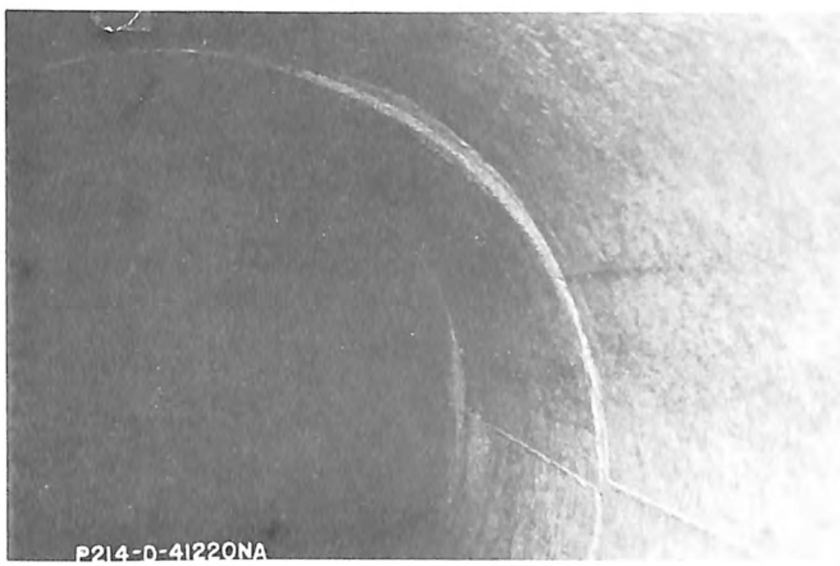


B. Vent in crown of 48-inch cast-in-place pipe, smooth mortar, Station 254+00.

Flow resistance coefficients cast-in-place pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT
Pipe vents and pipe interior surfaces



A. Surface of 36-inch cast-in-place pipe near Station 334+05, direction of flow away from the viewer.



B. Surface of 48-inch cast-in-place pipe showing mortared offsets near Station 260+50, direction of flow is toward the viewer.

Flow resistance coefficients cast-in-place pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT
Inside pipe surfaces and offsets

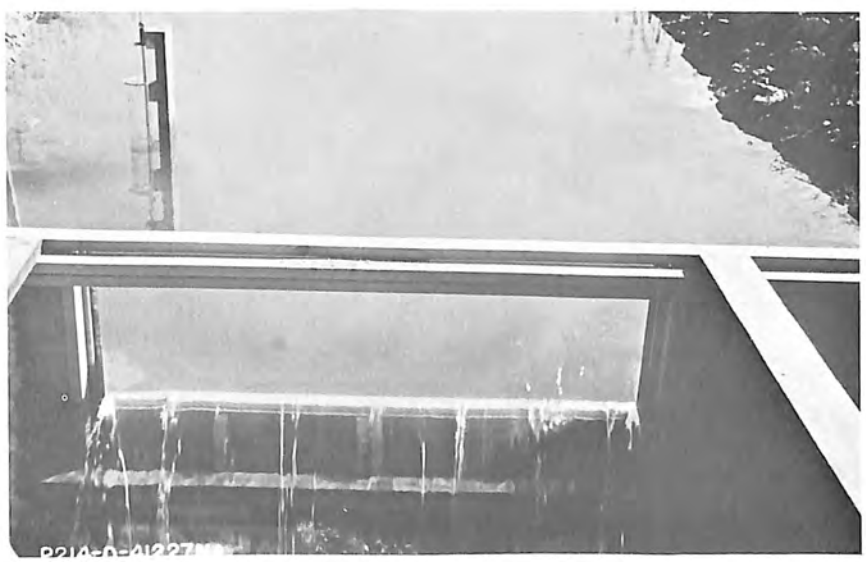
A. Six-foot-long fully contracted rectangular weir and head gage installed at road crossing transition structure, Station 173+80.

B. Weir performance with discharge of 24.9 cfs.

Flow resistance coefficients cast-in-place pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT
Weir installation

Figure 7
Report Hyd-533

A. Weir frame and bulkhead installed against road crossing transition structure.



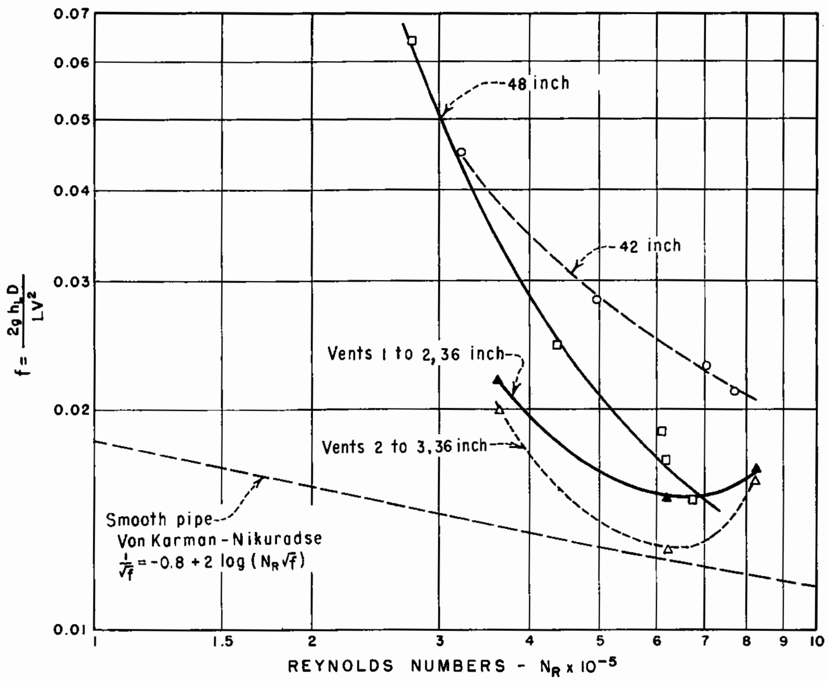
B. Weir performance with discharge of 10.7 cfs.

Flow resistance coefficients cast-in-place pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT
Weir bulkhead and head gage

A. Weir performance for nappe vented with discharge of 24.9 cfs.

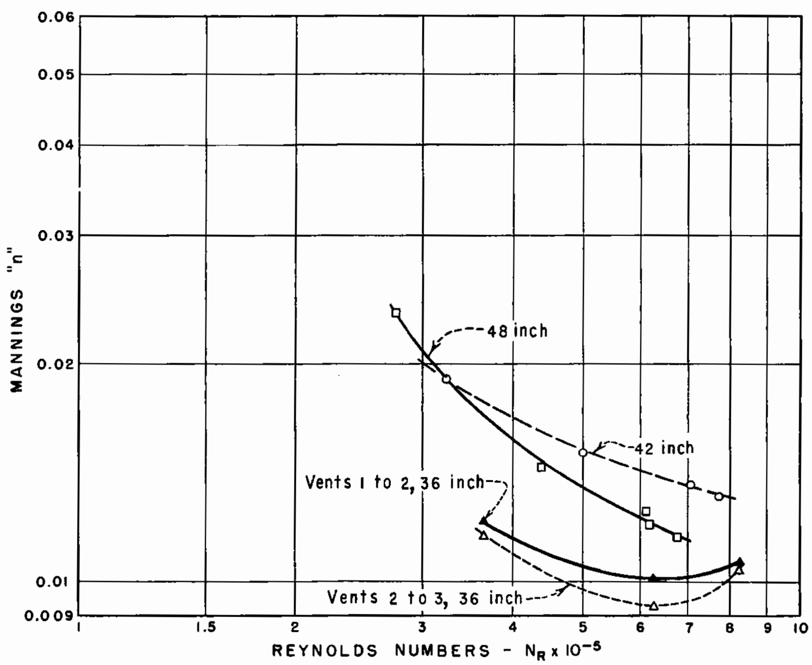
B. Electrical tape system for measuring water surface levels in pipe vents.

Flow resistance coefficients cast-in-place pipe
MADERA DISTRIBUTION SYSTEM--CENTRAL VALLEY PROJECT
Weir installation and electrical tape system



A. DARCY-WEISBACH FRICTION FACTOR

▲ - 36-INCH PIPE VENTS 1 TO 2 □ - 48-INCH PIPE ○ - 42-INCH PIPE △ - 36-INCH PIPE VENTS 2 TO 3



B. MANNINGS "n"

RESISTANCE COEFFICIENTS CAST-IN-PLACE PIPE

MADERA DISTRIBUTION SYSTEM-CENTRAL VALLEY PROJECT

VARIATION OF RESISTANCE COEFFICIENTS WITH REYNOLD'S NUMBER

7-1750
(10-64)

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second

Multiply	By	To obtain
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

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ABSTRACT

Hydraulic resistance coefficients were determined from head loss measurements made in 48-, 42-, and 36-inch-diameter cast-in-place concrete pipe installations. Data were obtained with the pipes flowing full at discharges less than the design values; from about 10 cubic feet per second to 25 cubic feet per second. Pipe test reaches varied from 1,240 to 3,895 feet. The hydraulic grade line was measured in 10-inch-diameter air vents used as piezometers; discharges were measured using a rectangular weir. Sufficient data were obtained to calculate flow resistance coefficients using the Darcy-Weisbach, Manning, and Scobey equations. The flow resistance coefficients for the 48- and 42-inch pipe and one reach of 36-inch pipe may contain residual losses produced by pipe entrance flow patterns, but the resistance coefficients for one reach of 36-inch pipe are believed to be representative of the values to be expected in long straight reaches.

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