BURIED facts

HYDRAULIC DESIGN CONSIDERATIONS

Concrete Pipe and Corrugated Metal Pipe

GENERAL

Culverts and Storm Sewers

Hydrology is the analysis of precipitation intensity, frequency, and runoff characteristics, and is the basis of culvert and storm sewer design flow determination so as to select the type and size of pipe to prevent or reduce flood damage. The subject of hydrology is adequately treated in many publications, and manuals have been developed for various areas. Even so, the federal government estimates that, in the United States, damage from floods exceeds several billion dollars each year. A significant portion of this damage can be attributed to selection of an inadequate size or type of pipe.

Sanitary Sewers

Design flows for sanitary sewer design are determined by empirical methods, based on historical data and projections of population and area use. The design flow is then used to select the type and size of pipe so as to prevent contamination from backups, flooded basements and expensive relief sewer construction. The results of surveys by the U.S. Environmental Protection Agency indicate conclusively that corrugated metal pipe is not commonly used for sanitary sewers and consequently there is a lack of performance data. Therefore, no comparison is possible with concrete pipe which has been used and performed satisfactorily for sanitary sewers in the United States for approximately one and one-half centuries. The performance deficiencies of corrugated metal pipe, readily apparent in culverts and storm sewers, however, would most certainly be problems in sanitary sewers.

Liberal policies for corrugated metal pipe are often promoted which are not equal to the generally more stringent requirements for concrete pipe. When the various design methods and criteria developed for the different materials available for sewers and culverts are considered, policy decision procedures can become exceedingly complex.

Satisfactory design methods must be based on theories, modified by model and full scale testing, and, most important, experience. Appropriate criteria involves relating requirements for usage and performance with, again, experience. Pipe policies generally have certain political and economic overtones, but should be based also on experience.

The proper design of sewers and culverts requires consideration of the different, but interrelated, fields of hydrology, hydraulics, structural behavior, durability and economics, and construction procedures. Knowledge of the performance of a pipe material in each of these fields is essential to complete evaluation and comparison. This publication compares the performance of smooth-wall concrete pipe versus rough-wall corrugated metal pipe on two basic hydraulic properties . . . culvert entrance losses and pipe wall roughness.

ENTRANCE LOSSES

Ponding at a culvert entrance not only causes upstream flooding, but also generates substantial hydrostatic uplift forces which often cause structural failure of light, flexible corrugated metal pipe. The depth of headwater allowable at the culvert entrance is selected to prevent flood damage to roads and property, but any headwater can cause uplift problems.

In culvert design, inlet geometry is an important factor, and the Federal Highway Administration publishes entrance loss coefficient values for various inlet configurations and pipe materials, *Table 1*.

The groove end of concrete pipe is much more efficient than the thin edge of corrugated metal pipe, with or without a headwall, and, as illustrated in *Figure 1*, enables more water to enter with less constriction of the flow. A smooth wall, coupled with an efficient inlet, results in a smaller size concrete pipe for culvert applications compared to a corrugated metal pipe with a rough wall and inefficient inlet.

As an example, using the culvert design nomographs in Federal Highway Administration Hydraulic Engineering Circular Number 5, for a 400-foot long culvert installed on a one-percent slope, and discharging 400 cubic feet per second within an allowable headwater depth of 11 feet, a 72-inch diameter concrete pipe, with a conservative roughness coefficient of 0.012 and the groove end projecting, is more than adequate. For equivalent flow capacity, a standard corrugated metal pipe two sizes larger (84-inch diameter) is adequate for the projecting end condition and a liberal roughness coefficient of 0.024. If the corrugated metal pipe were constructed of structural plate, with a liberal roughness coefficient of 0.032, a 96-inch diameter pipe would be required.

If the structural plate corrugated metal pipe diameter were the same as the concrete pipe, 72-inch diameter, water would pond 30.5 feet deep at the culvert entrance before it developed enough energy to push the water through the inefficient inlet and pipe barrel, *Figure 2.*

The extremely uneconomical procedure of first sizing the corrugated metal pipe and then specifying the same size concrete pipe has been a practice in some areas. As evident from the preceding examples, such procedures are completely in opposition to value engineering concepts, and a total waste of project funds whether from private investments or tax dollars.

ROUGHNESS COEFFICIENTS

In addition to pipe size, the hydraulic capacity of a drainage system is dependent on the pipe surface roughness. Because of

Table 1. Entrance Loss Coefficients.

Type of Structure and Design of Entrance	Coefficient, k_e
Pipe, Concrete	
Projecting from fill, groove end	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Groove end of pipe	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.1
Mitered to conform to fill slope	0.7
End-Section conforming to fill slope*	0.5
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall end wingwalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
End-Section conforming to fill slope*	0.5
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension	0.2
Wingwalls at 10° to 30° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7

*Note: "End Section conforming to fill slope", made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper have a superior hydraulic performance.

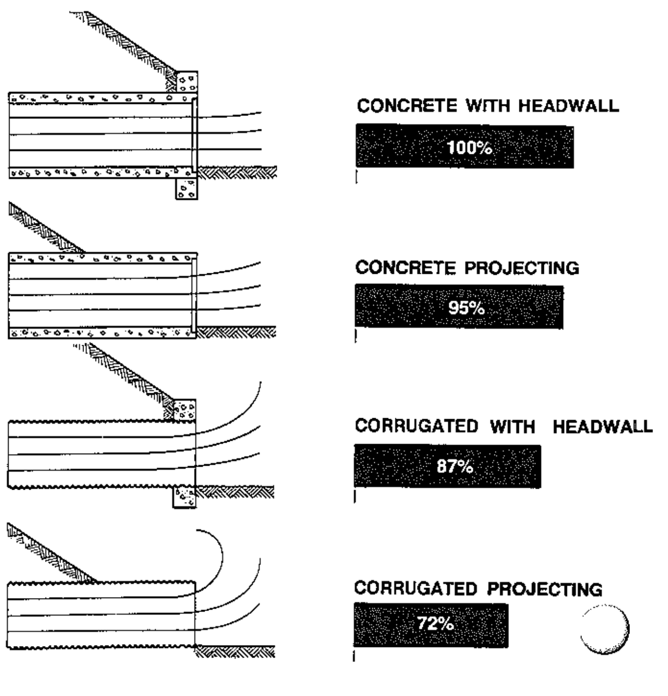

Figure 1. Effect of Inlet on Culvert Performance.

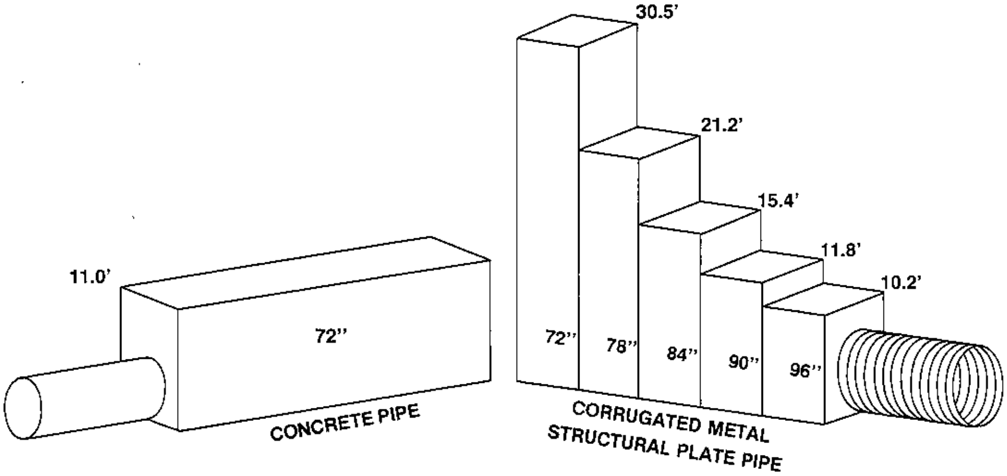

Figure 2. Effect of Inlet and Pipe Surface on Culvert Headwater.

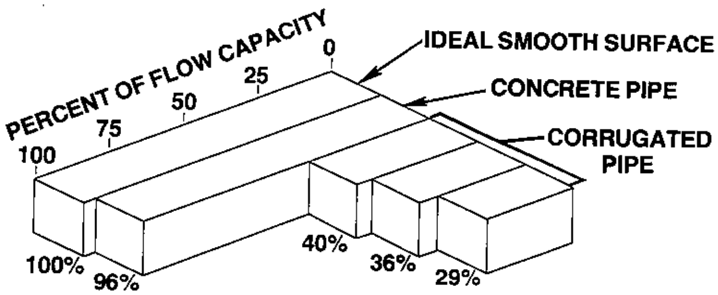

Figure 3. Effect of Pipe Surface on Flow Capacity.

this, extensive testing of concrete and corrugated metal pipe has been conducted by federal and state agencies and universities. Results prove that concrete pipe is hydraulically superior to corrugated metal pipe.

The effect of the roughness coefficients determined by these tests is apparent when the hydraulic capacities of concrete pipe and corrugated metal pipe are compared to that of a pipe with an ideal smooth surface, *Figure 3.* The relatively smooth surface of concrete pipe results in a flow capacity of 96 percent, while the rough wall of corrugated metal pipe results in flow capacities of 29 to 40 percent, depending on the corrugation pattern.

The significance of the hydraulic efficiency of concrete pipe is dramatically illustrated by comparing the capacities of 72-inch diameter concrete pipe and corrugated metal pipe installed on one-percent slopes. The full capacity of metal pipe with 6- by 2-inch corrugations, and roughness coefficient of 0.32, is 4.5 million gallons per hour, while that of concrete pipe, with a roughness coefficient of 0.010, is 14.8 million gallons per hour. Concrete pipe can handle 10.3 million gallons per hour more, which, for a storm lasting one hour, is enough water to flood 30 acres more than 12 inches deep.

In the preceding example, to obtain a flow capacity equivalent to concrete pipe, *Figure 4,* the diameter of corrugated metal pipe must be increased:

- 39 percent for 2⅔- by ½-inch corrugations.
- 41 percent for 5- by 1-inch corrugations.
- 45 percent for 3- by 1-inch corrugations.
- 56 percent for 6- by 2-inch corrugations.

LININGS

In an attempt to increase the hydraulic capacity of corrugated metal pipe, bituminous linings and pavings have been used to fill the corrugations. Bituminous linings and pavings have caused numerous problems because of lack of durability and adhesion, besides being subjected to abrasion, flammability and loss due to exposure to any one of a broad range of solvents. In many cases, problems have developed even before the pipe was installed.

Surveys by federal and state agencies have established the poor performance and limited service life of linings and coatings. Concern, not only with the possibility that drainage systems might be underdesigned, but also that the most economical material may not be specified because of improper cost comparison, has prompted states, such as New Jersey and New York, to require

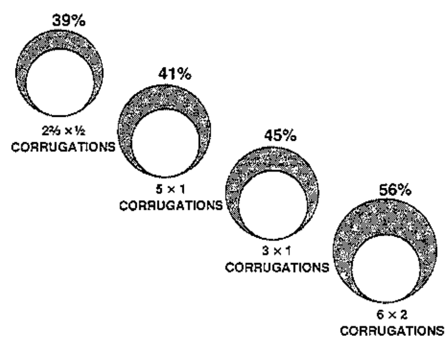

Figure 4. Increase in Corrugated Metal Pipe Size over Concrete Pipe Size.

that the hydraulic capacity of corrugated metal pipe be based on the roughness coefficient of unpaved and uncoated pipe, because these materials do not last for the life of the pipe. An authoritative discussion of lining materials and problems has been published by the Federal Highway Administration; Evaluation of Highway Culvert Coating Performance, Report Number FHWA/RD-80-059, June, 1980.

HELICAL PIPE

A few years after development of the spiral winding method of manufacturing corrugated metal pipe, a campaign was instituted to promote new hydraulic properties. The campaign claim is that the hydraulic capacity of corrugated metal pipe is increased by the helical corrugations which produce helical flow.

The claim is based on limited laboratory research conducted under the following specific conditions:

- Straight pipe sections, no bends nor junctions.
- Circular pipe sections, no deflections nor dents.
- Pressure flow, not partial nor just full.
- Clean water, no debris nor bedload.
- Bare pipe, no lining nor paving.

None of these conditions is expected in the construction and operation of gravity sewers. Without having all five of the above conditions present, the spiraling effect will not occur, and reduced roughness coefficients will not apply. As indicated in the Federal Highway Administration's publication, Hydraulic Flow Resistance Factors for Corrugated Metal Conduits, prudent design dictates the use of the same Manning's "n" value for helical as for annular corrugated metal pipe.

SUMMARY

Long life and little maintenance are important requirements for a value-engineered pipe product. Concrete pipe satisfies these requirements with the added benefits of being hydraulically efficient, non-combustible, corrosion resistant, construction adaptable, and structurally rigid and self-supporting.

Results of numerous impartial investigations present clear evidence of the potential problems with use of corrugated metal pipe. The best insurance for a trouble free project is to use concrete pipe. If alternate bids must be specified, it is imperative that the concepts of value engineering be applied, and a comparative life-cycle cost analysis be required.

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