# TAKING THE ROUGH WITH THE SMOOTH

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## SOME COMMENTS ON HYDRAULICS

The terms rough and smooth have special meanings in hydraulics and pipe materials. Pipes are classified as either rough or smooth wall. Smooth wall applies to concrete, clay, and plastics, while pipe with corrugated walls are considered rough.

Hydraulically, rough and smooth refer to the relationship between the pipe wall and the main flow. This relationship is influenced by the velocity and the size, or height, of any projection from the pipe wall into or beyond the area of the laminar flow sublayer adjacent to the pipe wall.

In sanitary sewers, most flows are in the low velocity category (2 feet per second minimum), and therefore the laminar flow sublayer adjacent to the pipe wall, being a function of velocity, is relatively deep. Figure 1 shows the effect of varying and increasing the size of the projections into the laminar flow sublayer.

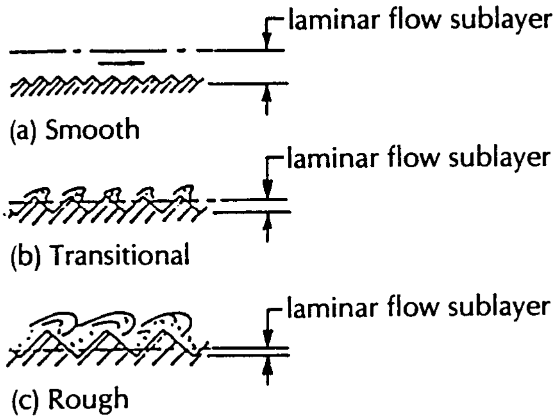



*Figure 1. Effect of wall projections on flow.*

We can make some conjecture as to the physical effect of projections, or roughness, by referring to Figure 1:

*(Figure 1(a)* (smooth wall) — The projections lie well within the laminar sublayer, which smooths out the flow and prevents any eddies from forming. The pipe behaves as though it were smooth, the actual size, shape and pattern of the projections being irrelevant.

*Figure 1(b)* (transitional wall) — The roughness is slightly larger than the thickness of the sublayer and therefore protrude out into the main flow region. Some eddying is caused which absorbs additional energy and increases the resistance to flow; the sublayer remains, however, substantially intact. This condition represents the transition between the smooth and fully rough zones.

*Figure 1(c)* (rough wall) — The projections are much larger and have only one-fifth or less of their height immersed in the sublayer. The projections create considerable disturbance and a turbulent wake, and a train of vortices are formed. The sublayer is almost completely disrupted and the drag due to the roughness is proportional to the square of velocity.

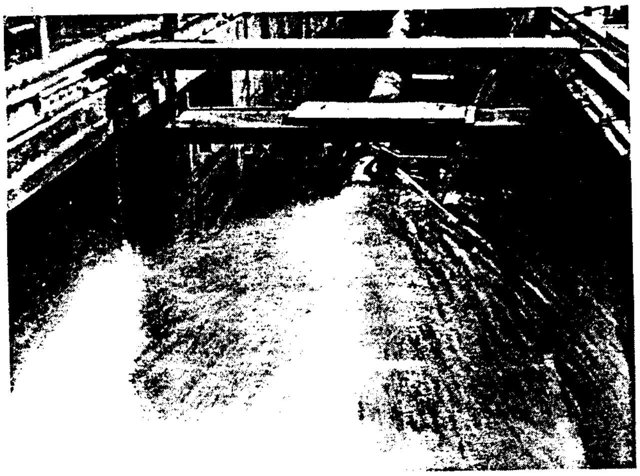
With the relatively low velocities experienced in sanitary sewers, and remembering that the effect of resistance to flow of a grain size of roughness particle is relative to velocity, it follows that for smooth wall pipe material such as PVC pipe and concrete pipe, there will be little difference in the efficiency of such materials in the transport of solids-carrying liquids, and thus the effects of field conditions will have the major effect on the hydraulic efficiency of a pipe. Field conditions that affect hydraulic efficiency include grade and alignment changes, manholes, tee and wye connections, and depositions and debris.

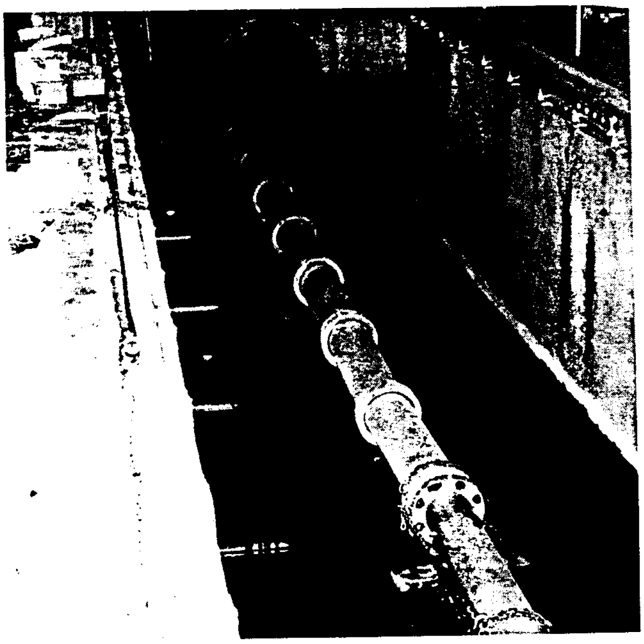
However, statements made by manufacturers of newer smooth wall pipe products imply hydraulic superiority for their products based simply on laboratory tests or conjecture. Consequently, the hydraulics of sewers has been the subject of more than a little controversy over the past few years.

Designers of sanitary and storm sewers have generally used Manning's formula:

$$V = \frac{R^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

The formula was devised by Robert Manning in 1889 and first published in 1891 in a paper presented to the Irish Institute of Civil Engineers titled "On the Flow of Water in Open Channels and Pipes."





The factor "n" is a coefficient which varies according to the hydraulic roughness of the pipe. Manning's formula has the benefit of simplicity and fits current practices of designing sanitary sewers for service at less than full capacity flows. The original formula modified to English units is universally used in North America:

$$V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

The concrete pipe and clay pipe industries and most reference authorities have recommended the use of a Manning's "n" of 0.012 for storm sewers and 0.013 for sanitary sewers even though laboratory research has consistently produced values for concrete pipe and other smooth wall pipes with laboratory results in the range of 0.009 to 0.010.

However, with the advent of these newer materials, particularly plastics, these manufacturers recommend the laboratory "n" factor for design. The use of laboratory values by designers results in a size advantage to plastic which cannot be reasonably justified, and can result in hydraulic problems in field installations with subsequent liability for the designer.

Let us examine the state of affairs which existed until 1986. The concrete pipe industry through publications of the American Concrete Pipe Association states:

> The difference between laboratory test values of Manning's "n" and accepted design values is significant. Numerous tests by public and other agencies have established laboratory values for Manning's "n". However, these laboratory results were obtained utilizing clean water and straight pipe sections without bends, manholes, debris, or other obstructions. The laboratory results indicated the only differences were between smooth wall and rough wall pipes. Rough wall, or corrugated pipe, have relatively high "n" values which are approximately 2.5 to 3 times those of smooth wall pipe.
>
> All smooth wall pipes, such as concrete and plastic, were found to have "n" values ranging between 0.009 and 0.010. Historically, engineers familiar with sewers have used 0.012 or 0.013. This "design safety factor" of 20-30 percent takes into account the difference between testing and actual installed conditions. The use of such design factors is good engineering practice, and, to be consistent for all pipe materials, the applicable Manning's "n" laboratory value should be increased a similar amount in order to arrive at design values.

The plastic pipe industry publications can be typified by those of the Uni-bell Plastic Pipe Association which recommends the use of Manning's "n" of 0.009 for hydraulic design of PVC pipe. This recommendation is based solely on experimental laboratory research and does not appear to take into account any field service conditions.

It was apparent that further information was needed to determine if there were any real differences in concrete pipe and PVC pipe both in the laboratory and in the field. The problem has been approached in three ways.

First, Consolidated Concrete Pipe Division commissioned the University of Alberta to undertake a study to determine the Manning's roughness coefficients for commercial concrete and plastic pipes. The instructions to the University were to determine the "n" values of concrete pipe in the sizes of 8, 10, and 15-inch diameters. The same methodology, equipment and techniques were to be used in an attempt to eliminate the effects of these variables. The study was carried out by Donald K. May, Bsc (Civil) in the T. Blench Hydraulics Laboratory under the guidance and supervision of Professors A.W. Peterson and N. Rajaratnan and published in January, 1986. The results were a Manning's "n" for concrete pipe of 0.010 and for PVC pipe of 0.009.

Secondly, another study commissioned by the American Concrete Pipe Association and carried out by the University of Utah obtained "n" values of 0.010 for 15 and 18-inch diameter concrete pipe.

Thirdly, a study commissioned by Sceptre Manufacturing Company, the Standards and Approvals Division of the Alberta Department of Environmental and the Sanitation Department of the City of Edmonton, was carried out under the control of the University of Alberta. The published report is titled "Field Measurements of Resistance Coefficients in Sanitary Sewers." The research was carried out by M. Joachim Besmehn under the guidance of Professor P. Bouthillier and Professor R. Gerard, University of Alberta. The study of 16 PVC and 6 concrete pipe sanitary sewers was conducted in and around the City of Edmonton. The field tests consisted of:

1. Discharge measurements using the continuous injection fluorescent-tracer dilution method.
2. Velocity measurements using the salt velocity method.
3. Flow depth measurement at the manhole using tape and weight.
4. Average slope measurement between manholes using rod and level.

The hydraulic roughness of each test section was determined using the Colebook-White equation. Unfortunately, while the actual flow levels at the beginning and end of the test sections could be determined with great accuracy, it was not possible to determine the flow profile between manholes.

The study resulted in some interesting numbers for Manning's "n". The average value of the observed field flow resistance for the PVC pipe and concrete pipe are listed in the following table:

| Pipe Diameter (inches) | Manning's "n" | |
|---|---|---|
| | PVC Pipe | Concrete Pipe |
| 8 | 0.018 | 0.018 |
| 10 | 0.019 | 0.016 |
| 12 | 0.017 | 0.018 |

We are all aware of the inherent difficulties of obtaining reliable field service flow experimental results because of the influences of unknown infiltrations, exfiltrations and changes in service flows, and consequently the real magnitude of these numbers may be in doubt. However, the numerical results can be legitimately used as a comparison of the field performance of the two materials, and it is rational to assume that whatever unknown variables, such as measurement technique, as were experienced, would apply equally to each type of pipe.

The results of the study showed that flow resistance in a pipe is significantly affected by more factors than just pipe material. These factors include pipe deflections, debris and solids in the flow, sediment on the pipe invert, slime on the pipe wall, manholes, connections, variation of grade and line, and post construction settlement. No real differences are apparent between concrete and plastic sewer pipes in field service conditions.

It is, therefore, reasonable to deduce that given laboratory values of 0.009 for PVC and 0.010 for concrete, the effects of field installation and other service conditions have a greater effect on flexible pipe than for rigid pipe. This deduction is supported by the consistently higher Manning's "n" for PVC than for concrete in the field service study, and certainly support the recommendation of the use of the same value for all hydraulically smooth pipe.

Let us look again at the comparative numbers. The PVC industry recommends the use of 0.009, which is the laboratory value, as a design value. However, the PVC industry commissioned study indicates the field service value varies 200 percent from the design recommendation. Concrete pipe has a laboratory value of 0.010, and the concrete pipe industry recommends 0.013 as a design value for sanitary sewers. The PVC industry commissioned study indicates the field service value for concrete pipe varies only 138 percent from the design recommendation. Even allowing for the errors in field measurements, there is no doubt that, in the installed condition, concrete pipe is more reliable and consistent than PVC pipe. This may be partially explained by the following factors:

a) concrete pipe is heavy and is more likely to retain line and grade as backfill is placed and compacted.
b) concrete pipe experiences no differential deflection at the joints.
c) joint frequency has no effect on Manning's "n".
d) both materials are in the hydraulically smooth category.
e) rigid concrete pipe is less affected by construction and post construction fill settlements.
f) concrete pipe remains circular, while flexible plastic pipe deflects.

To be successful, PVC pipe installations require greater compaction control and meticulous attention to backfill detail because it is light and easily displaced and deflected during construction. The necessary degree of compaction is difficult to obtain because flexible pipe deforms under pressure producing varying deflections with varying densities of soil. Problems of variation of line and grade resulting from all of the above cause a significant change in hydraulic efficiency. The "dimpling" which occurs on the inside surface of many flexible pipe products probably has a more serious effect on hydraulic flows than is currently understood.

Based on laboratory experiments, field studies and hydraulic theory, it is evident that all hydraulically smooth wall pipes — concrete, plastics, clay, and cement-lined cast iron — should be designed with the same Manning's "n" value. ■

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