TECHNICAL BRIEF

A Rational Approach to the Hydraulic Design of Pipe Conduits

Concrete Pipe Association of Australasia

Contents

ABSTRACT

Design formulae used in determining pipe diameters, particularly since the advent of the personal computer, are often interpreted with a great deal of precision. Often overlooked is the accuracy of the design flow which is derived from hydrological data, which may be even less accurate.

Commonly used hydraulic formulae are:

- Hazen-Williams
- Manning and
- Colebrook-White

Manufacturers often select inappropriate formulae together with parameters which show their product in the most favourable light and neglect important considerations such as actual pipeline diameter, the effects of silt and debris, joint eccentricities etc.

Preamble

The purpose of this document is to set out a series of technical and engineering facts concerning the relative discharge capacity of pipelines constructed from different materials. The document is concerned primarily with the selection of appropriate roughness coefficients for the calculation of pipeline capacity and the consequent selection of pipe diameter.

1 Introduction

There are numerous pipe flow charts and flow formulae available for use by pipeline designers. Indiscriminate use of these design tools can, however, result in errors in selection of pipe sizes. There is also the tendency for some designers to overlook important aspects of pipeline design such as selection of pipe roughness coefficients appropriate to specific in-service pipe conditions, and consideration of actual as opposed to nominal diameters. The accuracy of design flow estimates should be kept in perspective when choosing between various pipe sizes.

This document clarifies these points and provides designers with a rational approach for hydraulic design of pipe conduits.

2 Hydraulic Perspective

Design formulae which are used for determining the required diameter of a pipeline are often interpreted with a great deal of precision, but it is often overlooked that the starting point for such computations is the design flow - a parameter which is derived from often less accurate hydrological data using calculations based on methods such as the Rational Method (1).

The estimated flow rates are only as accurate as the data on which they are based. Evaluations of the accuracy of peak runoff estimates range from ±10% to ±25% in "Australian Rainfall and Runoff" (1) and from ±15% to ±25% in the "Australian Road Research Board" handbook (2).

For foul water sewer reticulation systems, uncertainties similarly arise in the estimation of the sewage flow. For example, the estimation of the daily sewage flow per household and the influence of infiltration into the sewerage system have a significant impact on flow estimates.

Described another way, inaccuracies in the selection of the design flow rates often overshadow differences in the computed pipe discharge capacities. For practical purposes, it is therefore necessary to accommodate theoretical discharges by a margin of say 5 - 10% before a change in pipe diameter can be justified.

3 Pipe Flow Formulae

When designing a pipeline or conduit carrying liquid, an engineer is faced with the choice of an appropriate flow formula on which to base the calculation. Some of the more commonly used formulae are:

- Hazen-Williams equation
- Mannings equation
- Darcy-Weisbach equation, incorporating the Colebrook-White equation for the determination of friction factor.

The Hazen-Williams and the Mannings equations are both empirical and contain dimensional coefficients which take account of the roughness of the conduit. Within the limited range of applications in pipe networks, stormpipe calculations, etc., the formulae are, in general, of reasonable accuracy (3).

The Darcy-Weisbach equation provides a more rational basis for flow computations. This equation is written as follows:

$$h_L = f \frac{L}{D} \frac{v^2}{2g}$$

where f = dimensionless friction factor

v = velocity

g = acceleration due to gravity

D = pipe diameter

L = pipe length

h_L = head loss over pipe length, L.

The friction factor, f, varies with the Reynolds Number of the flow and the relative roughness of the pipe except for fully-rough turbulent flow where f is independent of the Reynolds Number.

Early experiments on pipe flow carried out by Nikuradse (cited in (4)) enabled calculations of the friction factor:

These experiments incorporated pipes artificially roughened using sand grains to obtain the variation of the friction factor with Reynolds Number. This invaluable step provided a rational estimate of the actual roughness contributing to fluid friction or head loss in pipes under a range of flow conditions. Unfortunately, commercial pipe roughness differs from sand grain roughness in both shape and arrangement. However, Colebrook carried out experiments on commercial pipes, expressing the commercial pipe roughness in terms of an equivalent sand grain roughness size (5). The equivalent sand grain roughness is sometimes termed the Colebrook Roughness Coefficient, "k_S".

In conjunction with White, Colebrook developed an equation which described the variation of the friction factor with Reynolds Number for pipes of different equivalent sand grain roughness. This equation is now commonly referred to as the Colebrook-White equation, and in conjunction with the Darcy-Weisbach equation, is used in the calculation of head loss in commercial pipes. A graphical representation of the Colebrook-White equation is embodied in the so-called Moody Diagram which may be found in any textbook on pipe flow. The diagram permits a rapid solution of the implicit Colebrook-White equation.

4 Selection of Pipe Roughness

The following comments are based on the Colebrook Roughness Coefficient k_S mm. However, the comments are equally applicable to any other measure of roughness such as the Hazen-Williams "c" or Mannings "n".

4.1 – General

It is important to realise that, whilst the inherent surface roughness of a pipe is a property which could be expected to be a constant for a specific pipe, the roughness coefficient used in energy loss computations is a parameter which is dependent on both the pipe surface condition and the service conditions. For example, a pipeline in a specific installation flowing full will discharge a greater quantity of clean water than it will discharge if the water contains significant solids. The computation of pipe discharge under these conditions is achieved by use of two different roughness coefficients.

In selecting the value of the roughness coefficient, two notes in AS 2200-2006 (6) are important. Firstly, "Coefficients may need to be varied for any of the following reasons:

a. Biological growths and other obstructions.

b. Slime deposits, encrustation, detritus and other debris.

c. Deterioration of unlined ferrous surfaces, hence bore dimunition, by oxide.

d. Irregularities at joints such as:
- eccentricity
- abrupt decrease in diameter
- protrusions of mortar or other jointing materials.
- inadequate closure, especially if this has permitted tree roots to enter.

e. Amount and size of solids being transported.

f. Disturbance of flow from branches, especially in sewers." and secondly,

"In the choice of friction coefficients" (or roughness) "to suit an infinite variety of circumstances, the requirement of prime importance is educated engineering judgement".

Much of the available information regarding the magnitude of the roughness coefficient has been derived from experimental work carried out under laboratory conditions, using short pipelines and clean water. These conditions do not represent practical field installations for the reasons previously explained and therefore laboratory measurements of the roughness coefficient must be adjusted when applied to field situations. This approach applies irrespective of pipe materials.

4.2 – Clean water pipelines

Since slime growth and debris are not likely to be present in clean water pipelines, "k_S" values determined from laboratory tests are likely to be more applicable to the design of in-service pipelines, provided separate allowance is made for losses due to bends and fittings, etc.

For example, laboratory tests carried out on centrifugally spun concrete pipes indicate "k_S" values lie in the range 0.006

mm to 0.06 mm (7). By comparison, tests carried out on concrete pipelines in the field indicate "k_S" values actually lie in the range 0.09 mm to 0.12 mm (7). These higher values of "k_S" are attributed to head losses caused by bends and fittings. Designers can, when using concrete pipe, base their hydraulic calculations on "k_S"=0.06 mm (clean water) with separate allowances for fitting losses, or allow for losses by using an equivalent roughness coefficient. In the latter case, the Concrete Pipe Association of Australasia (7) has adopted a "k_S"=0.15 mm for field applications.

4.3 – Foul water sewers

For foul water sewers, the initial surface roughness of the pipe is often of no relevance because of the growth of sewer biological slimes on the pipe surface. The Hydrogen Sulphide Control Manual (8) indicates the thickness of the slime layers may range from 1mm to 5mm depending on flow velocity and location in the sewer.

Slime growth is also reported on the PVC lining of concrete sewers (for example, the Adelaide Trunk Sewer (9)), where such sewers are purportedly designed to maintain self-cleansing velocities.

Charackl et al (10) have shown that "microbial cells attach firmly to almost any inanimate surface submerged in an environment" and that there is a "coupled relationship between biological slime accumulation and hydraulics".

The effect of biological slimes overall, is to increase the equivalent pipe roughness coefficient. The Australian Wastewater Authorities Standing Committee (9) suggests that for a smooth sewer lining "the roughness is likely to be in the range 0.6mm to 1.5mm". A study by Clifford (11), showed that the roughness coefficient of an operating sewer rising main at Geelong ranged from 0.5 mm to 0.7mm. Other studies (12, 13 and 14) suggest even higher values of the roughness coefficient "k_S", up to 6.0mm, may be experienced in gravity sewers. Some quoted values of "k_S" include the effects of bends and pipe fittings.

As the "cost penalty" for adoption of a roughness coefficient of "k_S"=1.5mm compared with "k_S"= O.6mm is normally very small, the exercise of "sound engineering judgement" is to use a roughness coefficient of "k_S"= 1.5mm for gravity sewers, and "k_S"= O.6 mm for pumped mains where slime thickness is lower due to the higher wall shear under operating conditions which serves to strip back the slimes from the pipe wall.

These values are applicable to all types of pipe material.

4.4 - Stormwater drains

The selection of appropriate roughness coefficients for stormwater drainage is not precise because of the necessity to assess the effects of any debris which is carried by the stormflows. Unfortunately, but understandably, there is a dearth of relevant test data for in-service stormwater drains.

To design a stormwater drainage system without allowance for debris (that is, for clean water with "k_S"= 0.06mm for concrete pipe), represents an unlikely situation. Equally, the effect of debris on equivalent pipe roughness is unlikely to be as severe as the influence of biological slimes in a heavily slimed sewer. For these reasons the concrete pipe industry recommends the adoption of a "k_S" value of 0.6mm for most stormwater drain designs, but this value of "k_S" should be modified through engineering judgement where additional data is available. A value of "k_S" of 0.6mm is conservative compared with the "k_S" range (0.15 mm to 0.30mm) recommended in Australian Rainfall and Runoff (1), but again it should be noted that generally the cost penalty for adopting "k_S"= 0.6mm compared with 0.06mm is at most one step in pipe diameter.

4.5 – Analysis of manufacturers' technical information

Technical brochures from manufacturers of the following pipes have been analysed with regard to calculation of pipe discharge capacity:

- uPVC pipe AS 1712 (15)
- HDPE pipe to AS 1159 (16)
- "Hobas" GRP pipe to AS 2634 (17)
- Black Brute pipe (no AS/NZS standard) (18)

The first two technical brochures use the Hazen-Williams formula for the calculation of pipe flow. The old flow charts in the Hobas design manual and the Black Brute pipe brochure are both based on the Colebrook-White pipe flow equation. Further, the Hobas design manual is based on pipeline applications using water at a temperature of 20°C whereas the Black Brute pipe brochure is based on the temperature of the water being 15°C. Any comparison between the quoted pipe flow capacities is therefore difficult.

Only one value of roughness coefficient is nominated in each of the technical brochures with the exception of the Hobas design manual which nominates a Colebrook roughness coefficient of 0.10mm for pipelines conveying sewage and 0.01mm for other pipelines.

All literature refers to a given pipe for multiple applications – water supply and/or irrigation, sewerage, drainage and industrial applications. There are no qualifications on the flow chart published in the Black Brute pamphlets. The PVC and HDPE charts are qualified by "these charts are for straight pipes without fittings and carrying clean water at 20°C".

The Australian Standard AS 2200 (6) lists roughness coefficients for uPVC and polyethelene pipe as:

- Hazen-Williams 160-155
- Colebrook-White "k_S" 0.003-0.015
- Mannings "n" 0.008-0.009

The choice of "k_S"= 0.010mm for Black Brute is validated by quoting AS 2200 but does not provide data establishing that the values for smooth bore HDPE made to AS 1159 also apply to Black Brute. Laboratory tests by Tullis et al (20) suggest that corrugated HDPE pipe with a smooth liner (such as Black Brute) can have a Mannings "n" value in the range of 0.009 to 0.015. This is approximately equivalent to a "k_S" value ranging from 0.015 to 1.0mm. These tests were based on a subset of pipe sizes up to a maximum pipe diameter of 450mm.

The Black Brute flow chart typically gives a slightly higher discharge than the others but, within the accuracy of hydrological calculations all 5 pipe types could be considered the same. Further comment is based on Black Brute published information, but it is equally applicable to all the flexible pipes.

From the foregoing discussion it is appropriate that Black Brute pipeline discharges based on flow charts with "k_S"= 0.010mm should all be identified as applicable ONLY to clean water in straight pipelines without fittings, joint irregularities, bends, manholes, pits, etc.

For the flexible walled pipe materials, there is no evidence in the literature to suggest that joint irregularities have been considered in the selection of the equivalent pipe roughness coefficient. These joint irregularities (or eccentricities) tend to be more pronounced in larger flexible walled pipes and have been observed in a number of Black Brute pipeline installations (21) and (22).

Because of these joint irregularities, it must be questioned whether "k_S"= 0.010mm is appropriate even for long straight pipelines conveying clean water. It should also be noted that Australian Rainfall and Runoff adopts "ks"=0.060 mm for uPVC pipes with rubber ring joints (1).

It can be shown that deformation of a pipe to an elliptical shape reduces the area of waterway and hence pipe capacity. For an elliptical pipe deflection of around 6% the discharge is reduced by about 2%.

The available technical literature does not provide sufficient data to allow precise selection of roughness coefficients for the various conditions. For sewers and stormwater drains, llks" is obviously larger than 0.010mm, and in the absence of more quantitive data, it is recommended that the following values of the EQUIVALENT ROUGHNESS COEFFICIENT be adopted for sewers and stormwater pipeline design:

- Sewers 0.6 - 5mm
- Stormwater drains 0.6mm

The indiscriminate use of the published flow charts, based on "k_S"= 0.010mm, will in normal circumstances for sewer or stormwater drains, significantly over estimate the discharge of pipelines.

5 Culvert Design

5.1 – General

Calculation of the discharge capacity of culverts depends on whether the flow is occurring under inlet or outlet control conditions. Where the prevailing control is not obvious, the situation must be analysed separately, assuming inlet control and outlet control, and the results compared to determine the limiting discharge.

The following sections briefly describe these control conditions and the influence of culvert pipe equivalent roughness on the discharge capacity of the culvert.

5.2 - Culvert flow with inlet control

In short, steep culverts, flow may be restricted by inlet characteristics with the discharge controlled by the headwater depth and the geometry of the inlet. In effect, the inlet to the culvert behaves like an orifice. The dominance of the inlet causes part full flow in the remainder of the culverts unless, of course, the tailwater causes the culvert to be flooded under which conditions outlet characteristics control the flow.

For the inlet control conditions described, culvert surface roughness does not affect culvert capacity.

5.3 - Culvert flow with outlet control

Outlet control always occurs where the tailwater depth causes the pipe to run full and may occur in cases where the pipe runs part full. Under this condition, the culvert characteristics control the relationship between the flow of the drainage water and the head difference across the culvert, and nomographs have been developed which relate the energy head difference (H), entrance loss coefficient (ke), culvert length (L), pipe internal diameter (D), and surface roughness (as Mannings "n") to the culvert discharge capacity (Q). The nomograph in Figure 1 for pipe flowing full is taken from CPAA Hydraulic Design Manual (7) which is a metricated version of US charts (25).

This nomograph can be used to assess the effect of equivalent surface roughness on the internal diameter of a culvert pipe required for a given discharge under specified conditions of afflux. Shown in Table 1 are examples which have bee selected to provide reasonable coverage of a range of pipe culvert conditions.

The Mannings "n" values used in the analysis have been selected from AS 2200-2006 (6) as follows:

- Plastic pipe (HDPE, uPVC) - 0.008 to 0.009.
- Reinforced concrete 0.009 to 0.012 (with 0.011 the commonly adopted value),

The current version of the Standrd does not refer to corrugated metal pipe. The previous version , AS2200-1978, suggested the following: Corrugated metal pipe - 0.016 to 0.024; {with "n" = 0.024 being typical of annular corrugations whilst for helical corrugation "n" ranges from 0.016 at 600 mm diameter to 0.024 at 1500mm diameter (23)).

All the above selected Manning "n" values apply for clean water and new pipes. Should the water contain silt and debris the Mannings "n" values will have to be increased. As previously noted, Mannings "n" is not dimensionless and will depend on the size of conduit and velocity of flow as well as on surface roughness.

It can be observed from examination of Table 1 that:

- there is no significant difference between plastic and concrete pipe culverts where flow is controlled by outlet conditions.
- the required diameter of corrugated metal pipe culverts is generally one to two sizes larger than plastic or concrete pipe of the same hydraulic capacity.

This is illustrated graphically in Figure 2, based on the American Iron and Steel Institute publication (23). It is also significant to note that the actual diameters of concrete pipes are usually larger, than the nominal diameters given in Table 1.

Table 1 – Page 5 *(overleaf).*

Table 1: Comparison of pipe culvert capacities for varying conditions, without outlet control

Example	Culvert Design Parameters						Required Diameter (mm)	
No.	Q (m3/S)	ke	H (m)	L (mm)	Mannings "n"	Material	Calculated	Nominal
1	1.05	.05	2.0	40	.008 .009 .011 .012 .016 .024	plastic plastic/concrete concrete concrete helical corr. annular corr.	570 585 605 610 650 725	600 600 600 600 675 750
2	1.95	.05	0.29	40	.008 .009 .011 .012 .016 .024	plastic plastic/concrete concrete concrete helical corr. annular corr.	1160 1180 1200 1210 1275 1430	1200 1200 1200 1200 1350 1500
3	8.0	.02	1.07	30	.009 .011 .012 .016 .024	plastic/concrete concrete concrete helical corr. annular corr.	1610 1645 1650 1700 1800	1650 1650 1650 1800 1800
4	5.0	.02	1.0	100	.008 .009 .011 .012 .016	plastic plastic/concrete concrete concrete helical corr.	1360 1390 1420 1460 1550	1500 1500 1500 1500 1650

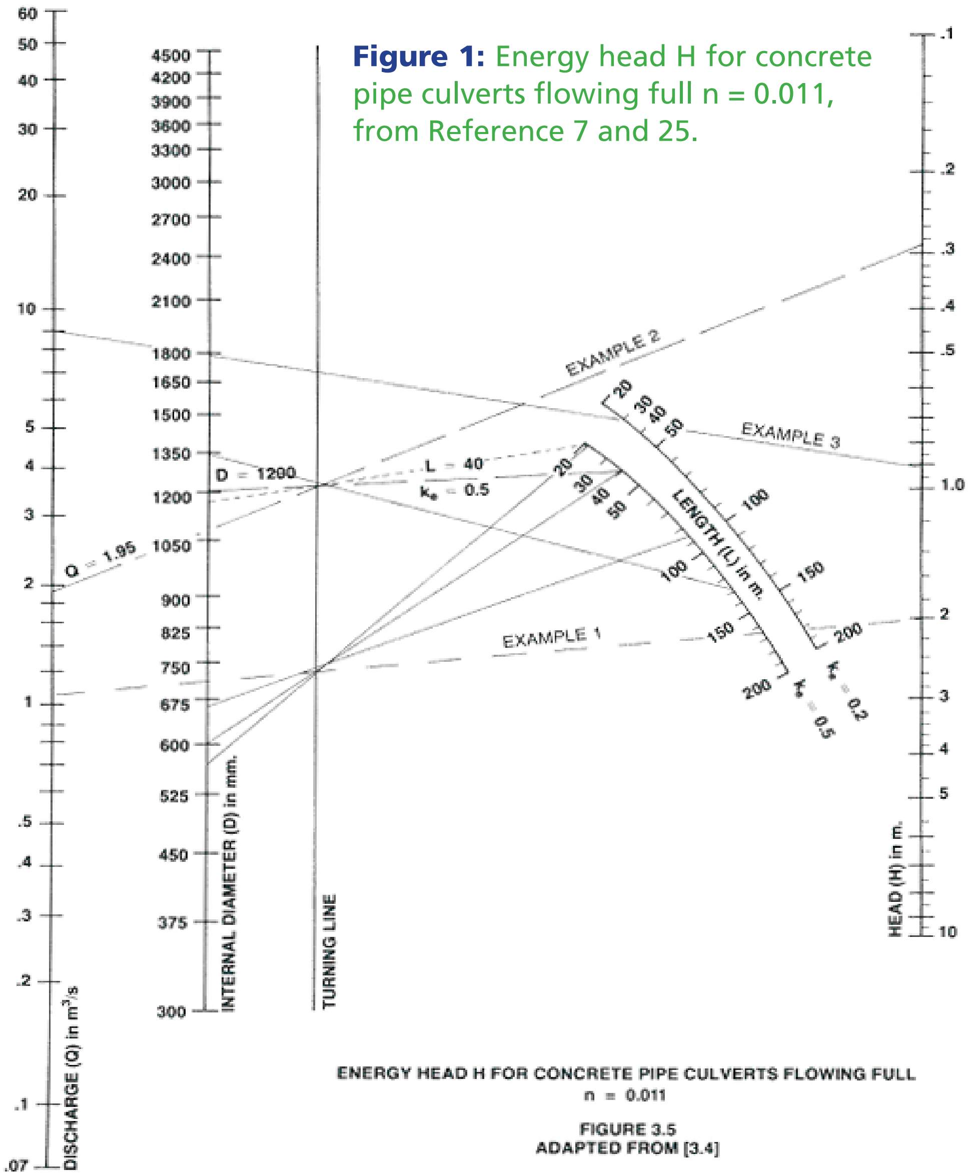
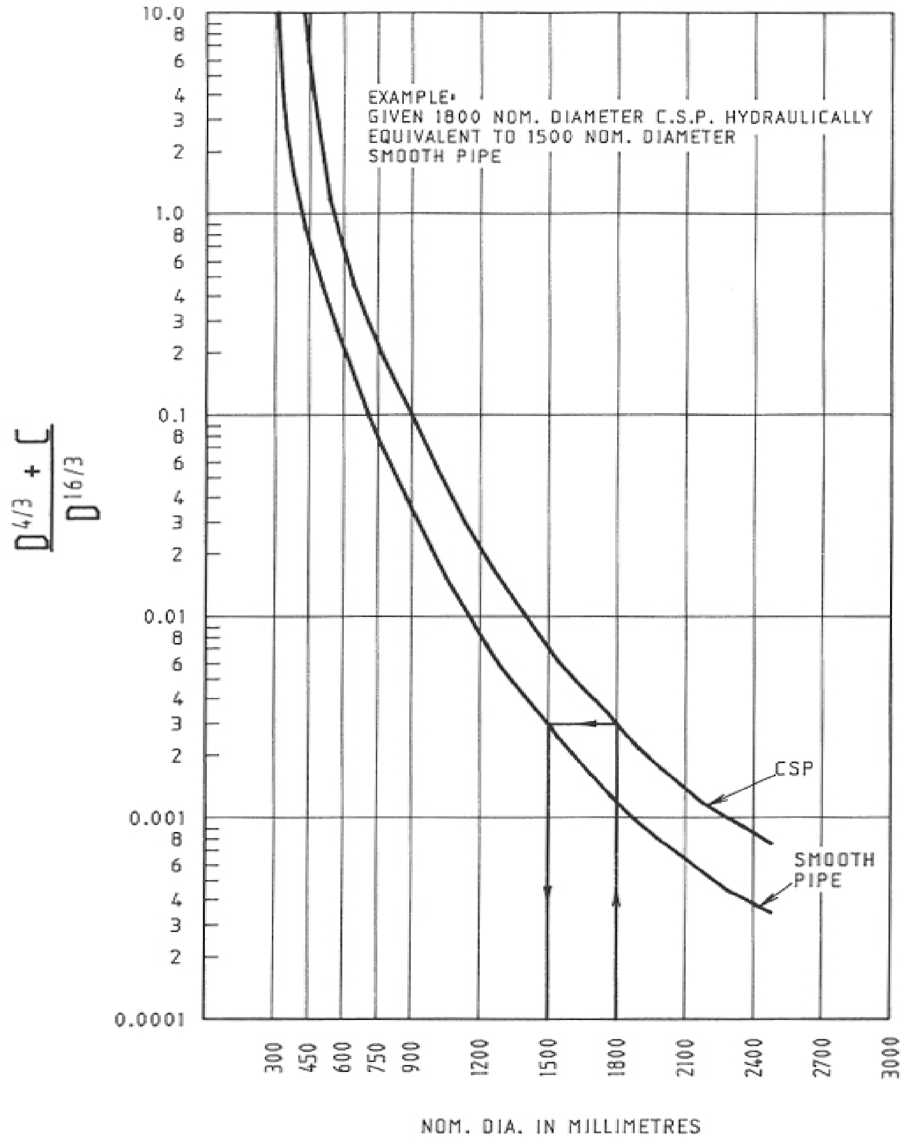


Figure 1: Energy head H for concrete pipe culverts flowing full n = 0.011, from Reference 7 and 25.

NOTE:
(a) For a different value of n, use the length scale shown with an adjusted length $L_1 = L\,(n1/n)^2$.
(b) For a different value of k_e connect the given length on adjacent scales by straight line and select a point on this line spaced from the two chart scales in proportion to the k_e values.

Figure 2: Comparison of required diameters of smooth concrete pipe culverts compared to corrugated metal culverts, from Reference 23.



6 Comparison of Discharges from Alternative Pipeline Materials

In any assessment of pipeline discharge there are two important factors:

- The roughness coefficient selected must be appropriate; and
- actual internal diameters should be used in the pipe flow calculations.

Misleading information has been published because these two fundamentals are often ignored.

For example the Black Brute brochure (18) quotes the maximum computed discharge capacity of 900mm pipe on a 0.5% energy slope as follows:

- HDPE - 854 L/s.
- Reinforced concrete -1665 L/s.

The equivalent roughness coefficient "k_s" used for HDPE has been taken as 0.010mm. This value lies in the middle of the range for "straight pipelines" carrying clean water (6). The "k_s" value used for concrete pipe has been taken as 0.10 mm, a figure which includes generous allowance for field conditions including bends, valves, fittings, etc. A "k_s" of 0.06mm is therefore considered more appropriate in this comparison.

The selection of pipe internal diameters in the above examples has also been misleading. By referring to the relevant pipe literature (24) and (18), the actual minimum internal pipe diameters are 890mm for HDPE and 908mm for Class 2 reinforced concrete pipe. (The 908mm is derived from actual diameter of 915mm with a tolerance of ±7mm).

Accepting that "ks"= 0.01mm applies to HDPE pipe and assuming that the pipe remains circular, substitution of the actual minimum diameters in the Colebrook-White formula gives discharges of:

- HDPE - 779 L/s.
- Reinforced concrete - 764 L/s.

These discharges are not significantly different.

In some situations, the discharge from reinforced concrete pipe is calculated to be higher than from plastic pipe -for example, for a nominal 450 mm diameter pipe on a 0.25% slope using actual minimum diameters (440 and 452 mm) and comparable "k_s" values (0.01 and 0.06 mm), the discharges are calculated as:

- HDPE - 194 L/s.
- Reinforced concrete - 197 L/s.

Again, these discharges are not significantly different.

In the above examples it has been assumed that the flexible walled pipes remain circular when installed in the ground. This is not strictly correct as pipe deflections do occur due to loading exerted on the pipe and due to long term creep.

As discussed in Section 4.5, pipe deflections can result in a reduction in pipe hydraulic capacity. For example, an elliptical pipe deflection of 6% in the two examples outlined above would reduce the capacity of the HDPE pipes to 1763 L/s and 190 L/s respectively. Hardie Iplex (18) generally allow for a maximum deflection of 7.5% for Black Brute pipes.

Actual deflections of flexible walled pipes would of course depend upon a number of factors including trench design, depth of pipeline, soil type, construction control, etc., and in many installations the maximum deflection may not be realised.

From the above discussion, it is clear that the claims in the Black Brute brochure that "this allows design engineers to use smaller diameter pipe" and that using concrete gives "an approximately 10% reduction in flow capacity" are not sustainable.

The facts are that for practical purposes and within the total uncertainties of computation of design flows, discharges from plastic and concrete pipes are equivalent, and nominal pipe diameters required in any given situation are the same.

7 Conclusion

In addition to the physical roughness of a particular pipe material, there are a number of other factors which must be considered when carrying out the hydraulic design of pipelines, such as the effects of slime growths, silt, debris, joint eccentricities, etc. These additional factors often result In the effective roughness of a pipe being significantly greater than that which is determined from laboratory tests using clean water and straight concentrically jointed pipes. In fact, the effective field roughness of a pipeline conveying sewage is independent of the pipe material. In pipe culvert design (for both inlet and outlet control conditions), the choice of pipe equivalent roughness has little bearing on the selection of pipe size, for both concrete and plastic pipes. For corrugated metal pipe culverts, the required diameter is generally one or two sizes larger than plastic or concrete pipe of the same hydraulic capacity.

Care should be exercised when interpreting pipe manufacturers' technical brochures as many of the brochures include charts and roughness coefficients which are only applicable to clean straight pipes conveying clean water.

It is also important that actual, as opposed to nominal, pipe diameters be used for hydraulic design calculations and designers are referred to the manufacturers' literature to obtain actual diameters.

Finally, the accuracy of the estimate of the design flow for a pipeline should always be kept in perspective when comparing the hydraulic capacity of pipelines constructed from alternative pipe materials. The assumptions used in establishing the design flow, the quality of pipeline construction, and the operating conditions of the pipeline throughout its economic life, are usually of greater significance than the roughness coefficient selected.

REFERENCES

1. Institution of Engineers Australia, "Australian Rainfall and Runoff", Vol. 1. Revised Ed. 1987, pp 10, 37, 324 and 325.
2. Argue, J., "Australian Road Research Board Special report No. 34 - Storm Drainage Design in Small Urban Catchments: A Handbook for Australian Practice", 1986, p 106.
3. Ackers, P., "Resistance of Flujds Flowing in Channels and Pipes", Hydraulics Research Paper No.1,1958.
4. Vennard, J.K. & Street, R. L., "Elementary Fluid Mechanics", Wiley, 6th Ed., 1982.
5. Colebrook, C.F., "Turbulent Flow Pipes, with Particular Reference to the Transition Region between the Smooth and Rough Pipe Laws", Jnl. Institute Civil Engineers, London, Feb. 1939.
6. Standards Association of Australia, "AS 2200-2006 Design Charts for Water Supply and Sewerage", p 22.
7. Concrete Pipe Association of Australasia, "Hydraulics of Precast Concrete Conduits, Pipes and Culverts: Hydraulic Design Manual", 1986 Ed., pp 40 and 67.
8. Technological Standing Committee of Hydrogen Sulphide Corrosion in Sewerage Works, "Hydrogen Sulphide Control Manual Septicity, Corrosion and Odour Control in Sewerage Systems", Melbourne Metropol itan Board of Works, December 1989, Monograph 2, Section 3, p 4,
9. Ibid, Monograph 9.3, Section 5, p 9 and Monograph 9.2, Section 9, p 11 .
10. Characklis, W.G., Cunningham, A.B., Escher, A.B. Crawford, D., "Biofilms in Porous Media", International Symposium on Biofouled Aquifers: Prevention and Restoration, American Water Resources Association, 1986, pp 57-78.
11. Clifford, T., "Head loss measurements on 450 mm sewer rising main", Geelong Water and Sewerage Trust, 1978.
12. Johnson, M., "A literature Review on the Effects of Slime in Sewers", The British Hydro-Mechanics Research Association, Crasfield Bedford England, 1980.
13. Perkins, J.A., Gardiner, I.M., "The Hydraulic Roughness of Slimed Sewers", Institute Civil Engineers, Part 2, Vol. 79, 1985, pp 87-104.
14. Bland, C.E.G., Bayley, R. W., Thomas, E. V., "Some Observations on the Accumulation of Slime in Drainage Pipes and the Effect of these Accumulations on the Resistance to Flow", Public Health Engineering, No. 13,1975, pp 21-28.
15. Humes Plastic brochure, "Flow Charts for uPVC. Pipes and Fitting", 1983.
16. Humes Plastic brochure, "Flow Charts for Polyethylene Pipes", 1983
17. Hardie Iplex, "Hobas Pipelines Manual", 1990.
18. Hardie Iplex brochure, "Black Brute Pipe", Flow Characteristics, pp 14 and 15.
20. Tullis, J.P., Reynolds, K., Watkins, Barfuss, S.L., "Innovative New Drainage Pipe", Preceedings of the International Conference on Pipeline Design and Installation, ASCE, March 25-27, 1990.
21. Goodman, W.J., (Consulting Engineer), "Inspection Report: North Lanyon Trunk Sewer", Unpublished, August 1988.
22. Fisher Stewart Pty Ltd, "Report on Inspection of HDPE Drain Lines Yarra Park", Unpublished, April 1991.
23. "Modern Sewer Design", American Iron and Steel Institute, 1980, pp 132- 133.
24. Humes Concrete, "Humespun Concrete Pipes", brochure, 1988, pp 8 and 9.
25. Bureau of Public Roads, Washington, USA, "Hydraulic Charts for the Selection of Highway Culverts", Hydraulic Engineering Circular, No's 5 and 10,1965

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