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SHAPE EFFECT ON BED-LOAD TRANSPORT IN PIPES

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Abstract

The nature of part-full flows in pipe sewers produces different channel shapes resulting in non-uniform shear stress distribution on the wetted perimeter. New experimental data were utilised to check the applicability of several available methods based on different shape parameters to predict bed-load concentration in pipe sewers.

Introduction

It is commonly known that the distribution of shear stress on the wetted perimeter of an open channel is not uniform. In pipe sewers this phenomenon occurs at part-full flows. In the case of sewers for no sediment deposition, the hydraulic radius, \( R \) (Mayerle et al. 1991, May et al. 1989) and hydraulic depth, \( D \), (Arora et al., 1984; Paul and Sakhuja, 1990) were used to represent the shape effects. The underlying assumption in using \( R \) is that the shear stress on pipe wall is uniform contrary to the real situation in part-full sewers. In using \( D \), instead of \( R \), Arora et al. (1984) attempted to take account the effects of free surface which is the main factor in introducing non-uniform shear stress distribution in open channel.

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In this paper new experimental data covering different pipe sizes at part-full flows with no sediment deposition were used to check the validity of using $R$ and $D_s$ to represent the shape effects on transport of sediment as bed-load.

**Experimental Equipment and Procedure**

Experiments were carried out in smooth (154, 305 and 450mm dia.) as well as artificially roughened (305mm dia.) pipe channels. Artificial roughnesses were made of sand of diameters ($d_{50}$) 0.5 and 1.0mm (tests in progress). Graded sand and gravel of diameters ranging from 0.5 to 8.3mm with average density of 2550 kg/m$^3$ were used. All experiments were carried out under part-full uniform flows covering proportional flow depths $(y/D)$ ranging from 0.15 to 0.80. The range of flow Reynolds numbers $(=4VR/v)$ was $1.3 \times 10^5$ to $4.6 \times 10^5$. The sediment concentration varied from 1 to 1450 ppm by volume.

**Analysis of Data**

Multiple-regression analyses were used to fit the present experimental (smooth pipes) data to a function given by Mayerle et al (1991):

$$\frac{V}{\sqrt{g d_{50} (S_s - 1)}} = f(C_v, D_{2t}, \frac{R}{d_{50}}, \lambda_s)$$

where $C_v$ is the volumetric sediment concentration, $S_s$ is the relative density of sediments, $\lambda_s$ is the Darcy-Weisbach's friction factor with sediment, and $D_{2t} (=d_{50} [g(S_s - 1)/v^2]^{1/3})$ is the non-dimensional grain diameter.

The data collected from 305mm dia. pipe channel yielded the best-fit relationship:

$$\frac{V}{\sqrt{g d_{50} (S_s - 1)}} = 4.15 C_v^{0.33} D_{2t}^{0.03} (\frac{R}{d_{50}})^{0.41} \lambda_s^{0.03}$$

with adjusted determination (adj. $r^2$) coefficient = 0.98.

The friction factor, $\lambda_s$, with sediment transport could be evaluated from a function proposed by Nalluri and Kithsiri (1992):

$$\lambda_s = f(\lambda_{cl}, C_v, D_{2t})$$

$\lambda$ being clear-water Darcy-Weisbach's friction factor of the channel which can be obtained by Barr's equation (Featherstone and Nalluri, 1988). The resulting best-
Figure 1. Verification of Eqn. 4 with other data

Figure 2. Verification of Eqn. 2 (R-model) with authors' independent data
fit equation was based on all of authors' data (adj. \( r^2 = 0.95 \)). Equation 4 was tested with the independent

\[
\lambda_2 = 1.26 \lambda_c^{1.01} c_v^{0.03} d_{97}^{0.01} = 1.26 \lambda_c
\]

(4)

data of Mayerle et al (1991) and May et al (1989) - see Figure 1 - resulting in a very good agreement.

Further analyses of data were carried out to fit a function used by Paul and Sakhija (1990), intended for various channel shapes:

\[
C_v = f \left( \frac{S}{v}, \frac{X}{d_{90}}, \lambda_s, \frac{D_h}{y} \right)
\]

(5)

where \( q \) is the unit discharge (=Q/T, Q and T being flow discharge and water surface width respectively), \( v \) is the kinematic viscosity of water, and \( S \) is the slope parameter (=S/(S-1) in which \( S \) is the channel slope). \( D_h \) is defined as the ratio of flow area, \( A \), to water surface width, \( T \).

The best-fit equation (adj. \( r^2 = 0.97 \)) was obtained from the 305mm dia. pipe channel data:

\[
C_v = 0.016 \left( \frac{S}{v} \right)^{0.03} \left( \frac{X}{d_{90}} \right)^{-0.36} S^{0.46} \lambda_s^{2.18} \left( \frac{D_h}{y} \right)^{-1.23}
\]

(6)

Verification of Transport Models

Validation of Eqns. 2 and 6 were carried out using independent data collected by the authors from smooth and rough boundary pipe channels of 154mm, 305mm and 450mm dia. These data were used to compute predicted parameter, \( C_v \) and plotted against its observed values.

Figures 2 and 3 show that Eqns. 2 and 6 predict reasonably well the authors' data collected from smooth 154mm and 450mm dia. channels as well as the data from rough \( (k_e = 0.53 \text{mm}, k_e \text{ being the equivalent sand roughness of channel boundary}) \) 305mm dia. channel.

In order to verify their validity for channel shapes other than circular, both models (Eqns. 2 and 6) were also used to the available data from smooth rectangular channels (Mayerle et al, 1991). Figures 4 and 5 show the predicted parameter, \( C_v \), in comparison with its measured values. Despite the poor correlation it may be concluded that the model based on hydraulic radius is in better agreement.
Figure 3. Verification of Eqn. 6 ($D_3$-model) with authors' independent data.

Figure 4. Predicted concentrations using Eqn. 2 ($R$-model)

Figure 5. Predicted concentrations using Eqn. 9 ($D_4$-model)
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Conclusion

The above analyses, within the range of current studies by the authors, suggest that either R or D, may be used to represent shape effects for bed-load transport in pipe sewers. Preliminary investigations of both models indicate the possibility of extending their uses over various channel shapes. It is suggested that this possibility to be examined once such data are available; however, model based on hydraulic radius seems to be more promising.

Appendix: References


