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Sediment transport of mixtures of cohesive and non-cohesive materials in sewer conduits

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ABSTRACT

Incipient motion and bedload transport of mixtures of cohesive and non-cohesive sediments in a circular sewer are investigated and analyzed from an extensive set of physical scale model tests.

Results show that increasing the amount of cohesive material in the mixture highers its erosion resistance and changes the erosion pattern from a pure non-cohesive to a more cohesive transport behaviour.

A multiple regression analysis based on the registered transport and the hydraulic parameters gives much better results than the traditional approaches for sediment transport calculations.

INTRODUCTION

Sediments in sewers are mostly composed of a great proportion of sand mixed with cohesive mud particles and a small amount of organic matter. Deposits in sewers occur when the transport capacity is insufficient to carry sediments continuously; especially during long dry weather flows. By a new event of rainfall, these deposited bed materials are eroded again.

In the Hydraulics Laboratory of Ghent, experiments with mixtures of sand, clay and water are carried out. The experimental results reveal essential similarities and differences between the non-cohesive and the

cohesive behaviour of the different kinds of sediment mixtures. Typical sediment transport phenomena and stream characteristics in the circular sewer flume are described and analyzed.

EXPERIMENTAL SET-UP

The experiments are carried out in a straight semi-cylindrical flume with a recirculating water system, having a total length of 11.15 m and an inner diameter of 390 mm as a model of practical sewer forms. Basically the model is divided in four parts: an inflow region, a movable bed zone, a sediment trap and an outflow region.

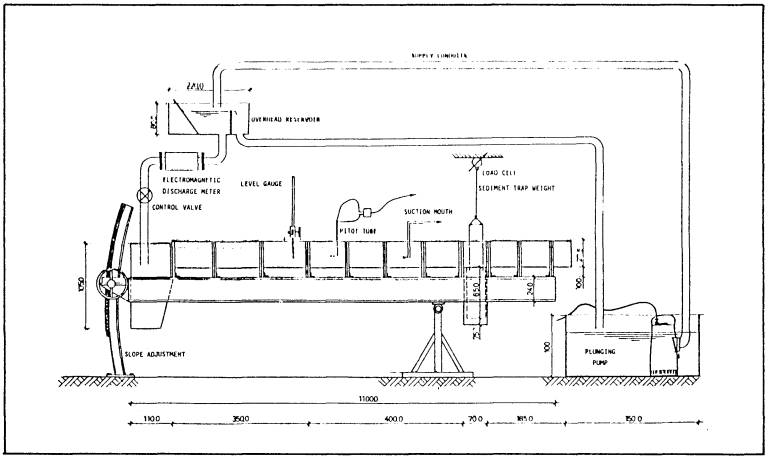


Figure 1. General overview of the test flume.

	MIXTURES		
	White Sand Pottery clay	White Sand China clay	Beach Sand Pottery clay
Number of tests	15	10	5
Range of % clay	0 - 30	0 - 30	5 - 20
Range of d_{50} (mm)	0.148 - 0.171	0.148 - 0.171	0.254-0.285
Range of slope (%)	0.128 - 0.246	0.246	0.128
Rel.bed thickness	0.10	0.10	0.10

Table 1. Experimental conditions of the tests.

Appropriate measuring devices register continuously the hydraulical and transport parameters of interest during the complete testrun. At the

upstream end of the flume, a special device is used to change the bottom slope. A general summary of the experimental conditions and the range of used sediment mixtures are shown in table 1. All experimental tests in the sewer model are executed with sediment mixtures of four basic materials : fine white sand, medium beach sand, white China clay mainly consisting of kaolinite and a montmorillonite pottery clay.

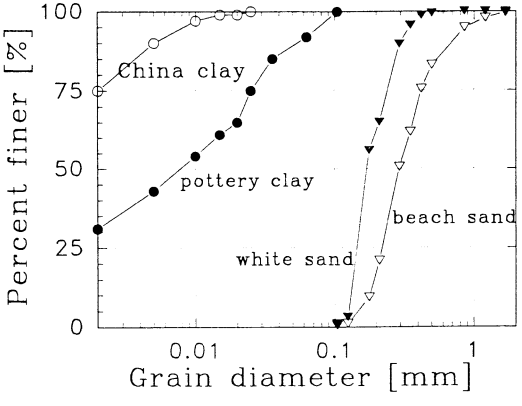


Figure 2. Sieve analysis of individual sediments.

GENERAL DESCRIPTION OF MIXTURE BEHAVIOUR

By increasing the amount of clay in a mixture, the sand bed is transformed progressively from a non-cohesive to a more cohesive sediment bottom. This typical variation depends not only on the type and content of sand or clay, but also on the sectional shape of the flume.

For lower clay contents (< 15 %), similar characteristics to those of the pure sands are noticed in the circular test flume. By highering the discharge, the fine clay particles of the bed material are washed out and the initial ripple forms develop to typical dune formations as a result of the intensive interaction with the side walls. These mixtures are considered as transitional. Further increase of clay content in the mixture shows smooth ripples or ripples with limited heights when the transport occurs. The sediment mixture is changing from a cohesionless to a more cohesive behaviour.

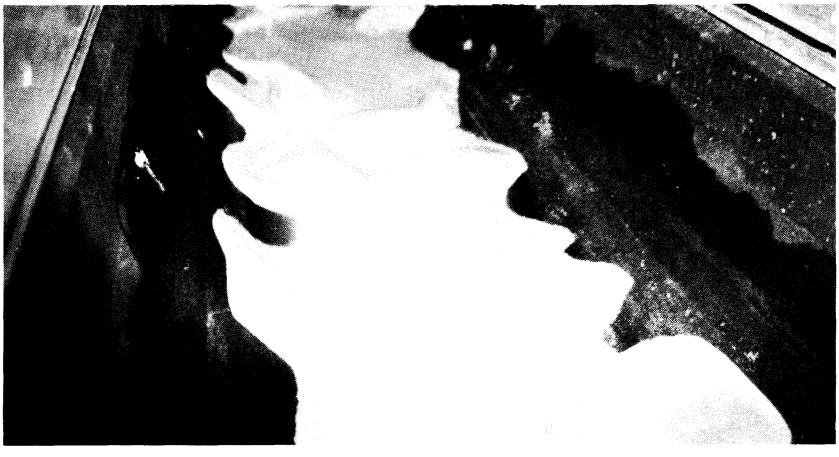


Figure 3. Typical bed forms in the circular flume.

INCIPIENT MOTION

During all experiments, the discharge in the test flume is highered step by step until initial erosion occurs. The critical shear stress is obtained by a linear extrapolation of the relation between the erosion rate and the corresponding shear stress. In general the critical shear stress increases with increasing clay content: the cohesive sediment in

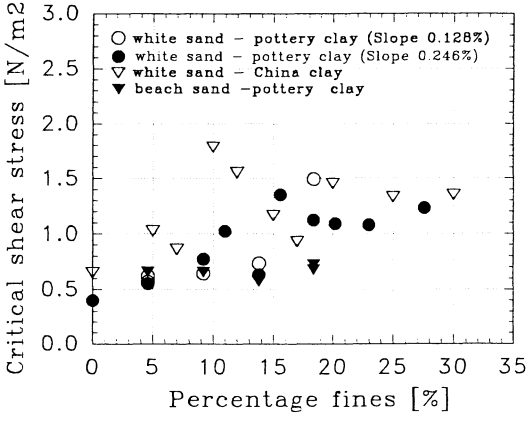


Figure 4. Incipient motion in circular test flume.

the mixture causes a significant increase in the resistance to erosion. As flow depths in Ghent are always smaller than half the pipe diameter, the channel shape effects on critical conditions are not noticeable.

SEDIMENT TRANSPORT

Various attempts are advanced to calculate the sediment transport of the mixtures based on the registrated erosion rates, the sediment characteristics and the mean hydraulic parameters.

A traditional non-cohesive sediment transport approach is used for all runs with typical bedform occurrence. Figure 5 shows the calculated transport rates using the traditional Einstein bedload formulae. These formulae seem to be quite successful for a certain reach of low clay contents. A large scatter in the figured sediment transport rates is noticed for sediment mixtures with a more cohesive behaviour. Similar bed load results are find with the Peter-Meyer and Müller formulation.

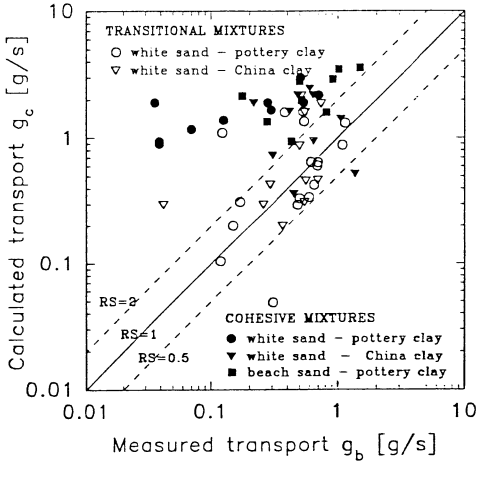


Figure 5. Einstein non-cohesive approach.

A general cohesive approach based on the traditional literature formula of Partheniades for all mixtures indicates an even worse consistency.

At the first sight cohesive mixtures, based on typical bedform occurence and erosional behaviour, don't really react as one should expect them to do, due to the secondary order phenomena in the test flume. The side wall interaction and the non uniform shear stress distribution in the circular flume section cause extra forces acting on the sediment bed. In order to cover not only the pure cohesive or non-cohesive sediment mixtures, a more general approach is followed. The expressions of the sediment transport of mixtures of cohesive and non-cohesive sediments are obtained using multi regression analysis. The general shields parameter is expressed in terms of the volumetric concentration (C_v), relative sediment size (d_{50}/R) and the friction coefficient (f). Using the mean values, the sediment transport in the circular flume is given by

$$\frac{\tau}{\rho (s-1) g d_{50}} = 0.0009\ C_v^{0.013}\ (d_{50}/R)^{-1.30}\ f^{0.40} \qquad (r = 0.89)$$

A simular transport approach for all experiments is calculated by using the bed hydraulic parameters

$$\frac{\tau_b}{\rho (s-1) g d_{50}} = 0.001\ C_v^{0.010}\ (d_{50}/R_b)^{-1.21}\ f_b^{0.36} \qquad (r = 0.92)$$

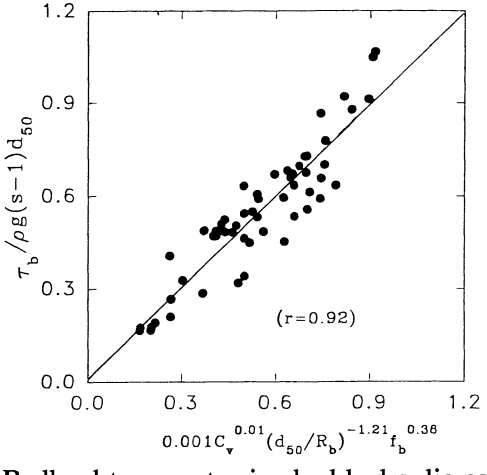


Figure 6. Bedload transport using bed hydraulic parameters.

In order to make a comparison with the results found by Alvarez and Nalluri for a gradual erosion process, the shape factor (h/P) is incorporated in the regression analysis.
No meaningful improvement of the correlation coefficient is found.
Using the mean hydraulic values or the corresponding bed parameters, we get :

$$\frac{\tau_b}{\rho g (s-1) d_{50}} = 0.0004\ C_v^{0.01}\ (d_{50}/R_b)^{-1.29}\ f_b^{0.34}\ (h/P)^{-0.22}$$

The independent terms and the power of C_v are seen to be strongly related to the sediment sizes, the relative bed thickness and the geometrical flume characteristics.
By this approach, a general transport calculation is formulated for sediment mixtures with a varying cohesive behaviour. A preliminar separation in cohesive and non-cohesive material, based on some artificial characteristics and visual observations, is no longer necessary to figure the sediment transport in sewer systems. By interpreting the multiple regression results, the specific form and dimensions of the experimental set up of this circular sewer flume must be kept in mind, since shape effects and side wall interaction play a very important role in the transport processes.

CONCLUSION

In sewer systems, the increase of the clay content in sediment mixtures makes the deposited bed to pass progressively from the non-cohesive behaviour to a more cohesive behaviour. A nearly linear variation of the critical shear stress with the cohesive clay content can be noticed.
To cover the complete range of the sediment mixtures, a general transport calculation using a multi-regression analysis is formulated. By that, a good correlation between the registered erosion rates and the hydraulic parameters is found for all experiments.

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NOTATION

C_v volumetric concentration $= \frac{g_b}{\rho_s Q}$

f mean friction coefficient

f_b bed friction coefficient

g_b measured bedload transport

g_c calculated bedload transport

h mean water height

P wetted perimeter

Q flow discharge

t bed thickness

D flume diameter

t/D relative bed thickness

R mean hydraulic radius

R_b bed hydaulic radius

R.S. $= g_c/g_b$

s $= \rho_s/\rho$

τ mean shear stress

τb bed shear stress