CHAPTER 302

A SLOPING DUCT FOR THE STUDY OF SEDIMENT TRANSPORT

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Abstract.

The details of a large sloping duct at HR Wallingford Ltd. are presented. The duct is capable of sloping to the angle of ±33° which exceeds the angle of repose of normal quartz sand. The duct can be tilted laterally as well as longitudinally so that; 1) the effect of combined slopes can be investigated; 2) the aspect ratio can be inverted. At present the duct operates with a steady flow but it can accommodate a wave piston.

1 Introduction.

An important aspect in modelling coastal morphology is the ability to describe the effects of sloping surfaces on sediment transport rates, for example due to longshore bars, dune and ripple formations, dredged channels and trenches and beaches. The research carried out to date is limited, and to remedy this HR Wallingford Ltd has constructed a unique facility to permit the measurement of sediment transport at steep slopes in a controlled environment.

2 Description.

The sloping sediment duct has been purpose-designed for conducting tests on sediment transport on horizontal beds, and shallow and steep slopes up to the angle of repose for the sediment. It has a maximum longitudinal tilt of ±33° and can be tilted, or turned, laterally up to this angle for sediment transport studies where a transverse slope is required. In figure 1 the duct is shown at

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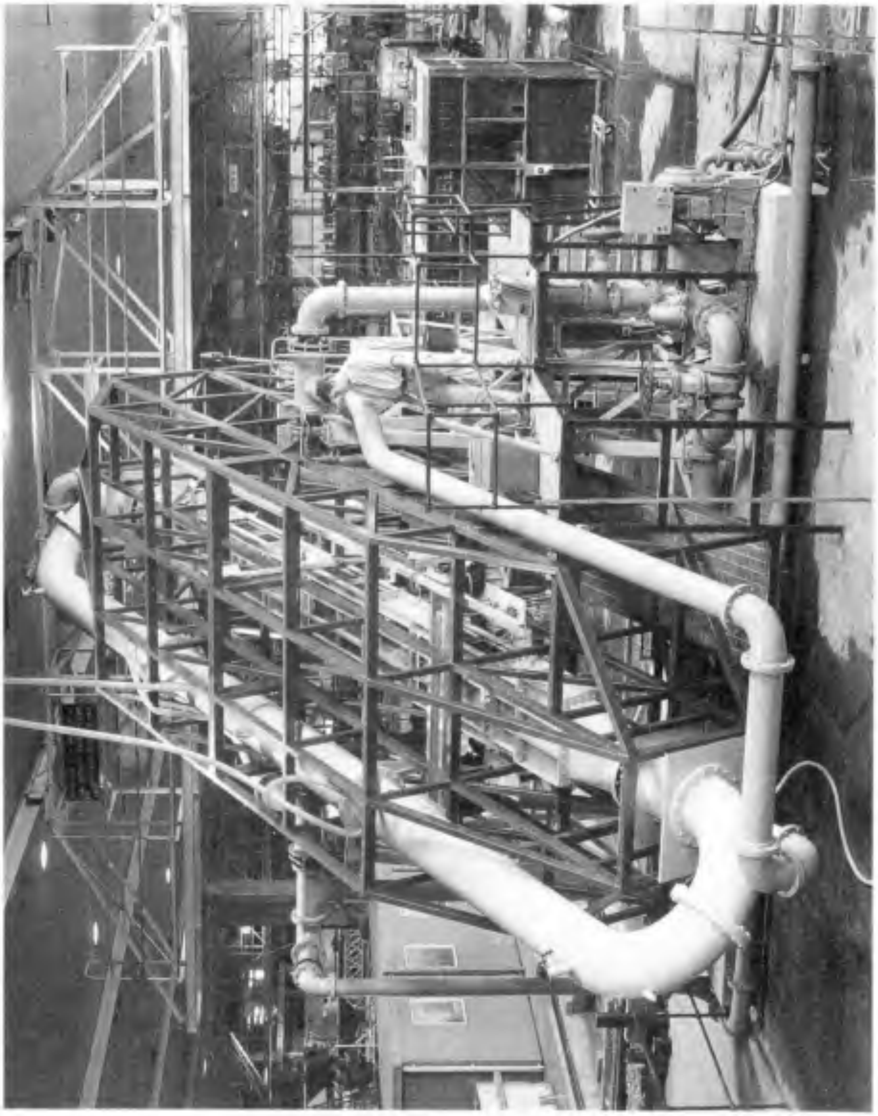

Figure 1: Sloping duct at maximum downslope setting.

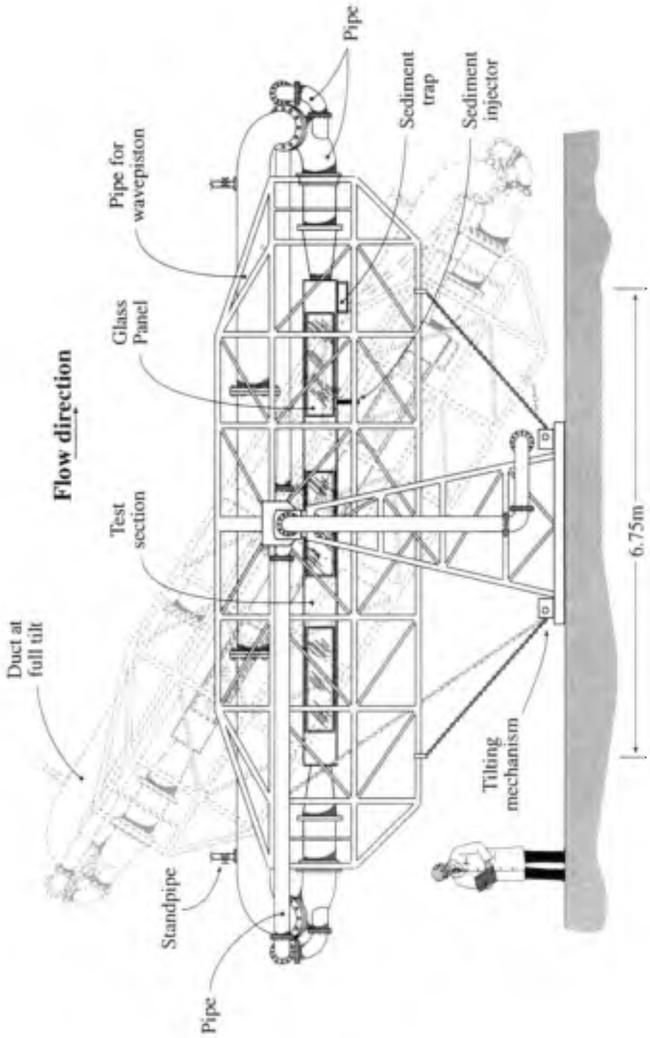

Figure 2: Drawing of sloping duct (not to scale).

full downslope (in the direction of the flow) tilt. The duct consists of a support cage, a test section and a central support on which the support cage pivots. See figure 2.

The dimensions of the test section are 6.75 m long by 0.6 m wide by 0.25 m high with three sections fabricated with glass viewing windows. The ends of the working section have rotating joints, and by tilting the duct laterally through 90° the aspect ratio can be either 1:2.4 or 2.4:1. The downstream end of the duct has a sediment trap which can be emptied by removing a cover plate.

The pump is a P76 centrifugal pump with the following characteristics: maximum head = $13m$ @ zero flow, design rating = $9m$ @ $0.17m^3/s$ and head corresponding to the maximum discharge =$5.3m$ @ $0.21m^3/s$. The maximum discharge corresponds to a mean flow velocity of approximately $1m/s$ in the duct. The system is a closed conduit with a stand-pipe to avoid water hammer effects.

The flow discharge is measured by an ALTOFLUX K380 electromagnetic flowmeter situated in a straight portion of the $8inch$ ($0.20m$) diameter feeder pipework. In each end of the test section there is a small pressure outlet. A Sandhurst Scientific $20mbar$ differential pressure transducer (GA 64/20E) is used to determine the total head loss in the test section. The distance between the outlets is $5.57m$ and for a mean velocity of approximately $1m/s$, the head loss is of the order $1cm$. An absolute pressure transducer (Druck PDCR 930) is installed in the middle of the test section. Provision has been made for mounting a two component Laser Doppler Anemometer (LDA). The laser mounting system rests on rails and can be moved along the test section. An electronically indicating point gauge is installed on the laser mount in order to determine the vertical position of the LDA with an accuracy of $\pm 0.01mm$. Seeding material for boosting the LDA signal can be introduced into the duct while it is operating.

At present the system operates with a steady flow, but it is designed to accommodate a wave piston which will allow oscillatory flows to be generated with periods and amplitudes corresponding to full-scale near-bottom wave motions.

3 Hydrodynamics.

The hydrodynamic properties of the duct have been investigated as a part of the ongoing research. Of particular interest for the sediment transport research is the wall shear stress. For all the experiments that have been conducted so far the floor of the duct has been covered by PVC plates onto which a quartz sand with a median grain diameter of $208\mu m$ has been glued. The sidewall correction method of Vanoni and Brooks (1957) has been used to partition the total pipe friction into wall and bed shear stress. The shear stress has been estimated through head loss measurements obtained by the differential pressure transducer and through LDA measurements in the constant stress layer. It turned out that the variance on the shear stress estimate obtained via head loss measurements was much larger than that of the estimates derived from LDA measurements. Therefore the results

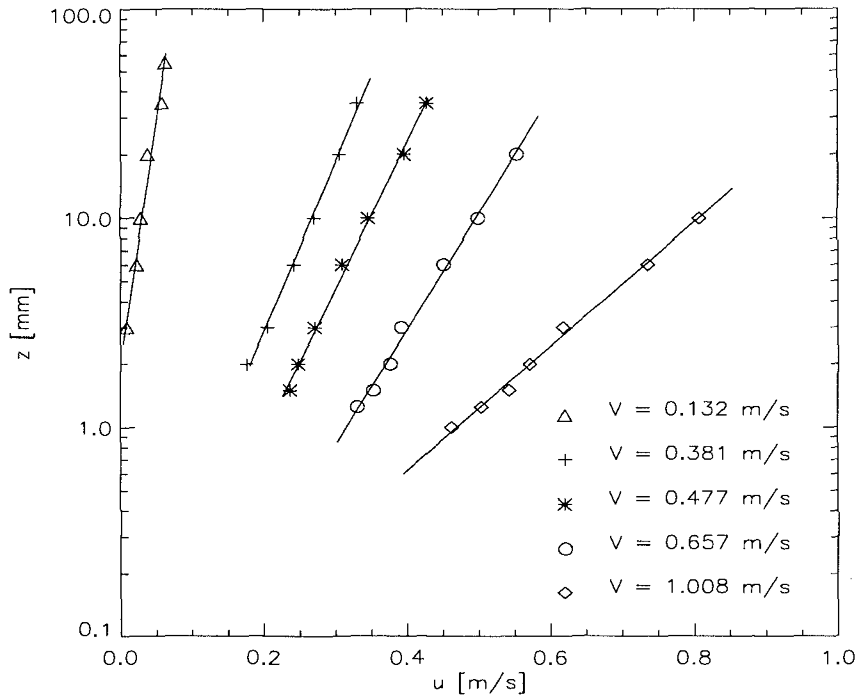

Figure 3: Vertical profiles of mean horizontal velocity measured with the LDA

obtained from the LDA measurements were used to establish the particular pipe friction relation for the duct. The procedure is as follows. First a vertical velocity profile is measured for a range of different discharges. The measuring points in the vertical profile should lie above the viscous sublayer but beneath the core region. See Schlichting (1960) for details. For each discharge the bed friction velocity, u_{*b}, is determined assuming a logarithmic velocity profile

$$\frac{u}{u_{*b}} = \frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right) \tag{1}$$

where u = mean horizontal velocity at distance z above the bed, κ = Von Karman's constant and z_0 = the bed roughness length. A number of velocity profiles are shown in figure 3 for different values of V, mean flow speed, $V = Q/A$, where Q = discharge and A = cross-sectional area.

The bed friction values obtained by equation 1 can be used to estimate the overall pipe friction by applying the sidewall correction method of Vanoni and Brooks (1957). These results have been compared with the Colebrook and White formula (Colebrook, 1939) and a modified version of the C&W formula where the theory of Christoffersen and Jonsson (1985) was used to account for the effect of uniform grain roughness and where a different value of the constant was used (1.94 rather than 1.74):

$$\frac{1}{\sqrt{\lambda}} = 1.94 - 2\log\left(\frac{k_s}{R}(1 - e^{-\mathbf{Re_g}/27}) + \frac{18.7}{\mathbf{Re}\sqrt{\lambda}}\right) \tag{2}$$

where λ is the resistance coefficient, $\lambda = 8(u_*/V)^2$, $\mathbf{Re_g} = u_* k_s/\nu$ is the grain Reynolds number, k_s = the Nikuradse equivalent sand roughness, equal to the median grain diameter of bed material, $\mathbf{Re} = 4RV/\nu$ is the pipe Reynolds number and R = hydraulic radius = A/p, p = wetted perimeter. The results are shown in figure 4 using axes based upon Colebrook's original paper.

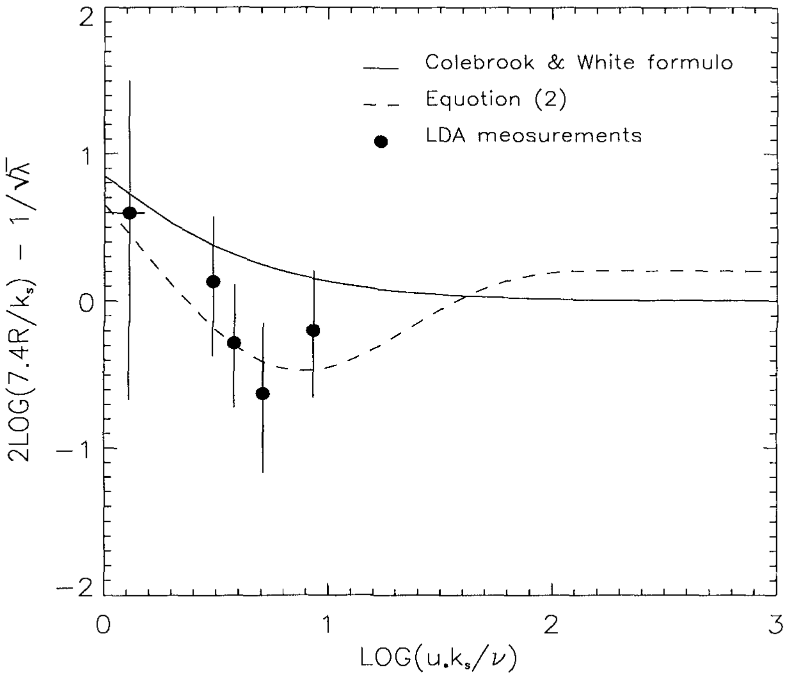

Figure 4: Friction diagram for the sloping duct with a rough floor.

4 Current research.

A study of bed-load transport (erosion rate) on sloping beds in steady flow has been conducted as a part of the MAST G8M Coastal Morphodynamics Project. It is for that purpose that the rough bottom mentioned previously was installed.

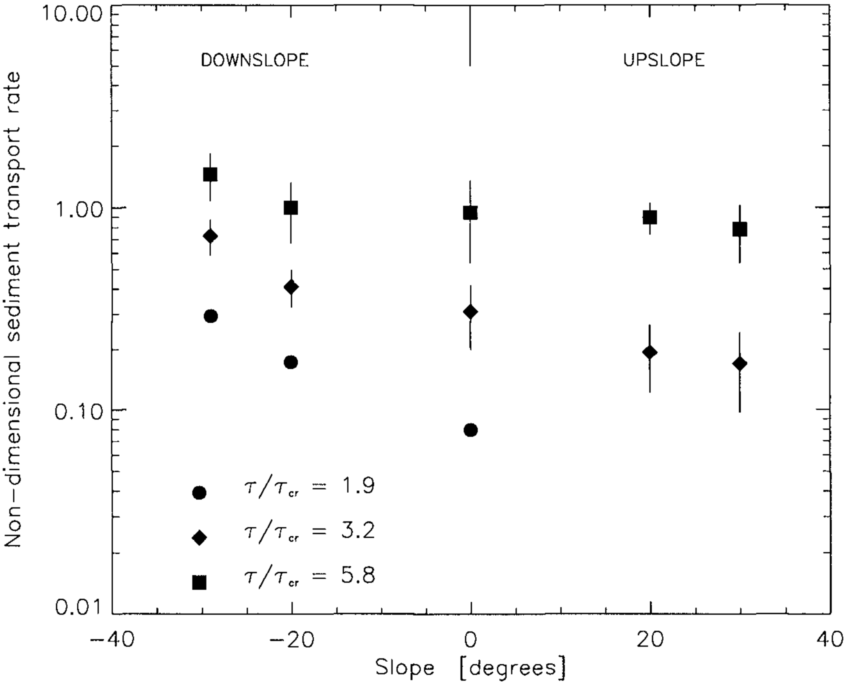

Figure 5: Experiments on slope effect on bed-load sediment transport. The values of τ_{cr} are for a horizontal bed.

An electronically driven sediment injector was installed downstream from the centre of the duct with an inner diameter of 20 mm. This device was used to inject sand into the flow to determine the equilibrium pick -up rate for sediment by the flow. The speed of the piston was adjusted until the rate of delivery of sediment matched the rate of removal by the flow. A porthole in the roof of the duct above the injector could be opened to charge the injector with sand and to make observations. At the downstream end of the test section the sediment trap captured the sediment injected into the flow. Figure 5 contains some results obtained in the duct for a range of bedslopes and shear stresses. The bed shear stress, τ, is given as $\tau = \rho u_{*b}^2$, and τ_{cr} is the critical shear stress for initiation of sediment motion on a horizontal bed. The results of this research are discussed further in Damgaard et al. (1996).

5 Conclusions.

The new sloping duct facility at HR Wallingford Ltd has proven to be suitable for large-scale experimental tests with sediments and can also be used for hydrodynamical research. The unique sloping capability of the facility allows the influence of gravity due to a sloping bed (of an arbitrary angle) on the sediment transport to be investigated for all types of sediment. The recent research has concentrated on a fine sand but the duct would be equally suitable for working with gravels as the flow speed achievable is up to $1m/s$.

It is expected that the duct will continue to be used for steady flow tests and, in the future with the addition of a wave piston, for wave or wave-current sediment or hydrodynamic investigations. The duct is currently available to European researchers through the EC Training and Mobility of Researchers - Access to Large-Scale Facilities - programme and it is anticipated that the facility will become available for wider usage by UK and other researchers in the near future.

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