INCIPIENT MOTION OF SEDIMENT PARTICLES OVER LOOSE DEPOSITED BEDS IN A RIGID RECTANGULAR CHANNEL

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ABSTRACT

New experimentals work were conducted to study the effects of sediment deposits' thickness on the incipient motion of particles in a rigid rectangular channel. The results show that the deposits' thickness significantly affects the channel's ability to erode the sediment deposits. New equations were derived taking into account the effects of deposits' thickness.

KEYWORDS

Incipient motion; sediment deposits; rigid channel; Erosion; storm drains; Flash flood.

INTRODUCTION

Rapid development in major towns in Malaysia results in the construction of new drainage system mainly open monsoon or storm drains to cater the increase in surface runoff.

A constant minimum velocity of 0.9 m/s is recommended by the Department of Irrigation and Drainage, Malaysia to minimize sedimentation problems. However, recent studies (Ab. Ghani et.al, In press) in the cities of Ipoh and Alor Setar confirm the presence of loose deposited beds of non-cohesive sediments in rigid open storm drains. Also, the sediment deposits have been found to be a major cause of flash flood due to the loss in the hydraulic capacity of the drains.

This paper highlights the results of experimental work to study the ability of rigid channels to start eroding deposited sediments. New equations were developed to ensure the channel is able to regain its hydraulic capacity even with the presence of sediment deposits.

AVAILABLE INCIPIENT MOTION EQUATIONS

Critical velocity (V_c) or shear stress (τ_c) is normally used to describe the incipient motion of sediments in both rigid and loose boundaries.

Rigid boundary

Novak and Nalluri (1984) proposed the following equation based on experimental works in circular and rectangular channels using different sizes of non-cohesive sediments :

$$\frac{V_c}{\sqrt{g\, d_{50}\,(S_s - 1)}} = 0.50 \left(\frac{d_{50}}{R}\right)^{-0.40} \qquad (1)$$

where d_{50} is the mean sediment size, R flow hydraulic radius, g the gravity acceleration constant and S_s the specific gravity of sediment.

El – Zaemey (1991) conducted experimental work in a circular channel having a flat rigid bed utilising several sizes of non-cohesive sediments and obtained the following equation :

$$\frac{V_c}{\sqrt{g\, d_{50}\,(S_s - 1)}} = 0.75 \left(\frac{d_{50}}{R}\right)^{-0.34} \qquad (2)$$

Loose boundary

Van Rijn (1984) proposed the following function to express the Shields' curve :

$$\frac{\tau_c}{\rho g\, d_{50}\,(S_s - 1)} = f\,(D_{gr}) \qquad (3)$$

where ρ is the density of water and D_{gr} (= d_{50} (g (S_s – 1) / $\nu^2)^{1/3}$; ν is the kinematic viscosity of water) the dimensionless sediment size.

EXPERIMENTAL WORK

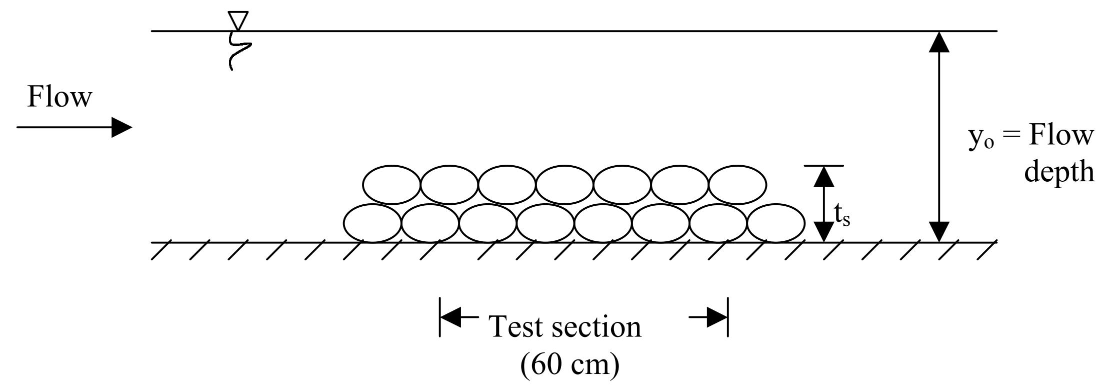
The sediments used were non-cohesive and uniform with sizes ranging from 0.55 mm to 4.78 mm which are commonly found in the storm drains in Malaysian cities (Ab. Ghani et. al, In press).

Experimental work were carried out in a rigid rectangular channel with a width (B) of 300 mm and a depth (D) of 450 mm. The channel has a length of 10 m.

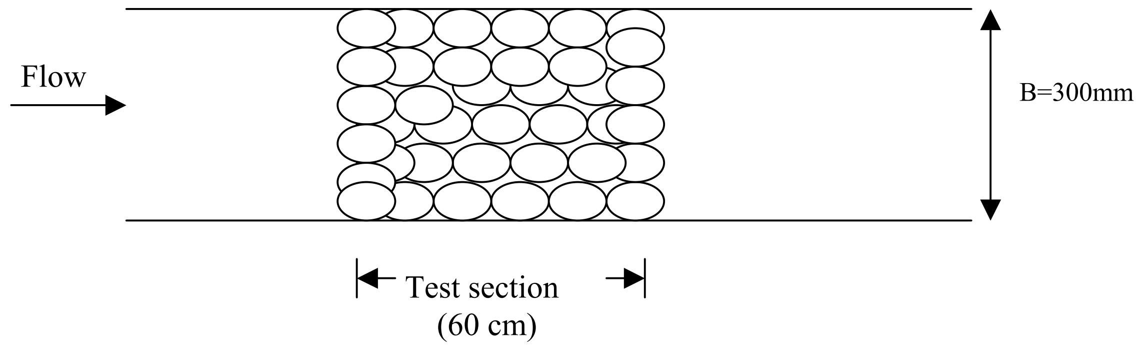
Initially sediment particles were positioned in one layer (i.e. sediment thickness, $t_s = d_{50}$). Later the particles were placed in different thicknesses namely 5 mm, 10 mm and 24 mm. In all experiments the sediment particles were spread over the channel width along a test section located in the middle of the channel (Figure 1). In each experiment flow was introduced and increased slowly. Uniform flow was maintained by adjusting the downstream gate.

A total of 120 experiments were conducted for all these thicknesses of sediment bed. The ranges of experimental work are $0.20 < V$ (m/s) < 0.60, $0.55 < d_{50}$ (mm) < 4.78, $S_s = 2.50$, $13 < y_0$ (mm) < 170 where V is the flow velocity and y_0 the flow depth.

The incipient motion of sediment particles was characterized by general movement of particles in all parts of the test section (Figure 1). A slight increase in the flow discharge was done to ensure erosion of the sediment particles do occur.



(a) Side View



(a) Plan View

Fig.1. Configuration of Sediment Particles.

RESULTS AND DISCUSSIONS

Evaluation of available equations

Figures 2 and 3 show the assessment of equations by Novak and Nalluri (1984) and El – Zaemey (1991) for bed thickness equals the sediment particle size ($t_s = d_{50}$). It can be seen that better prediction of measured V_c is given by El – Zaemey's equation (2). It seems that the presence of a flat rigid bed in a circular channel tends to simulate the incipient motion condition in a rigid rectangular channel. It should be mentioned that El – Zaemey (1991) used a similar range of sediment sizes as those of the present experiment.

Figures 4 and 5 show that the prediction of measured V_c by El – Zaemey's equation (2) becomes less accurate with the increase in sediment bed thickness. These results show that new equation is needed to take into account the presence of different thicknesses of sediment particles in the channel.

Derivation of new equations

Initially the following function used by Novak and Nalluri (1984) and El – Zaemey (1991) was utilised with the new experimental data :

$$\frac{V_c}{\sqrt{g\, d_{50}\,(S_s - 1)}} = f\left(\frac{d_{50}}{R}\right) \qquad (4)$$

Utilising all new data the following equation was derived :

$$\frac{V_c}{\sqrt{g\, d_{50}\,(S_s - 1)}} = 1.07\left(\frac{d_{50}}{R}\right)^{-0.23} \qquad (5)$$

with r (= coefficient of correlation) = 0.81.

Another equation was derived using Van Rijn's function :

$$\frac{\tau_c}{\sqrt{\rho g\, d_{50}\,(S_s - 1)}} = 0.17 \quad D_{gr}^{-0.57} \qquad (6)$$

with r = 0.82.

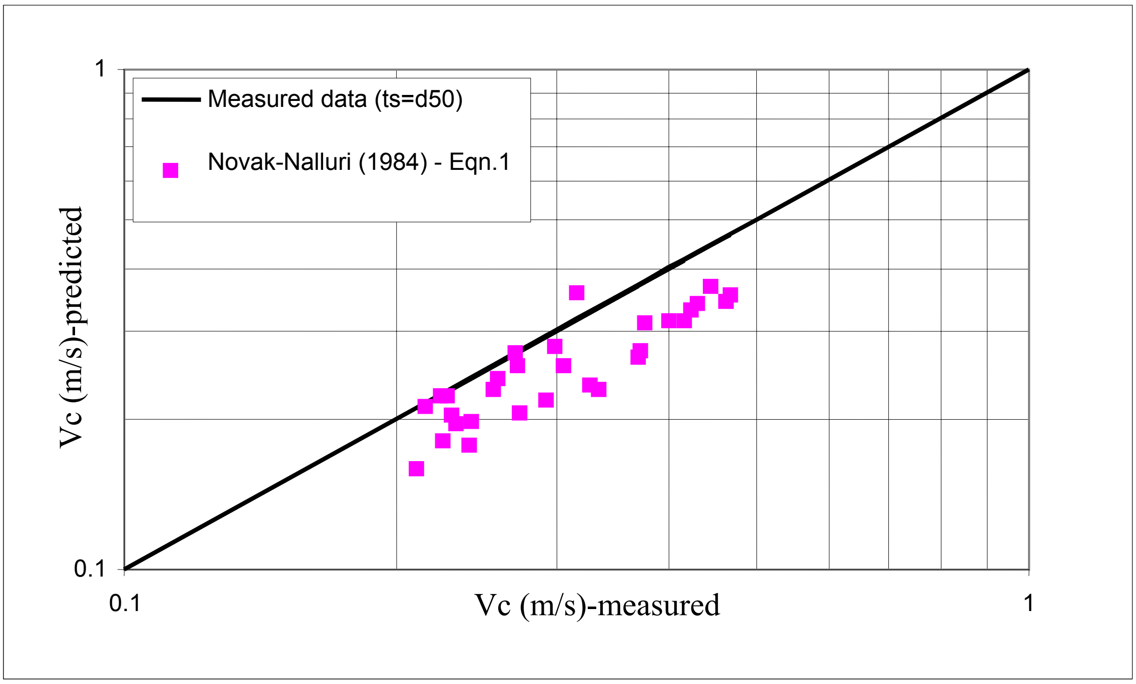


Fig.2. Comparison between the measured against the predicted critical velocity (Novak and Nalluri, 1984) – $t_s = d_{50}$

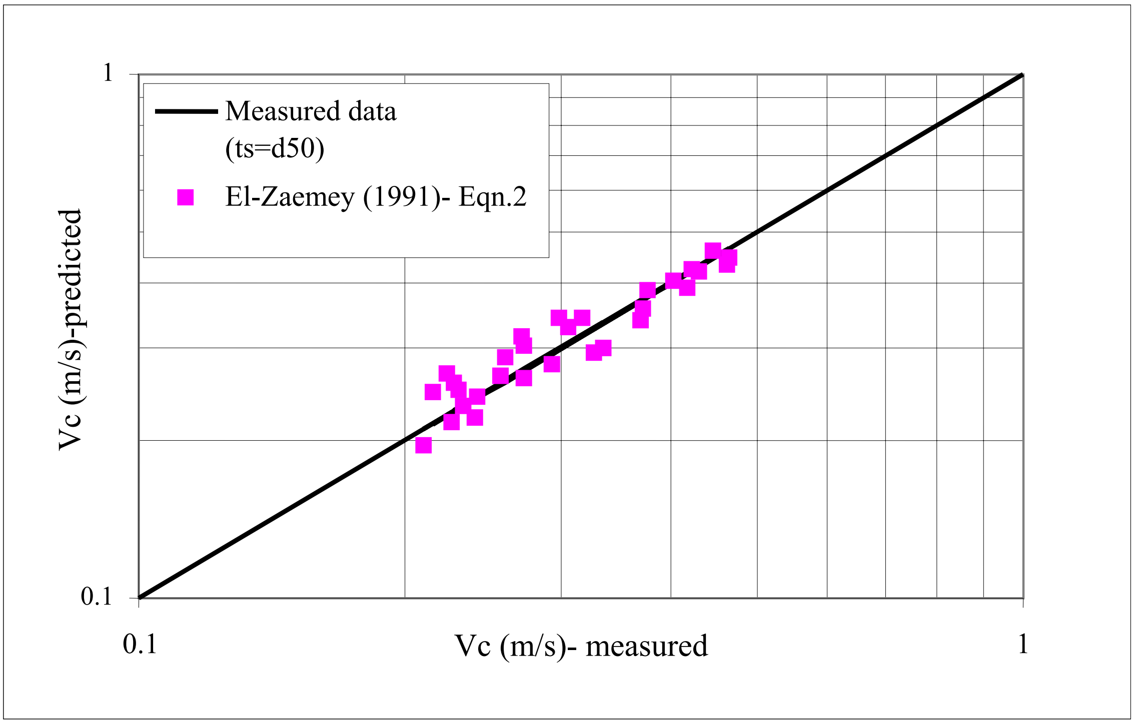


Fig.3. Comparison between the measured against the predicted critical velocity (El – Zaemey, 1991) – $t_s = d_{50}$

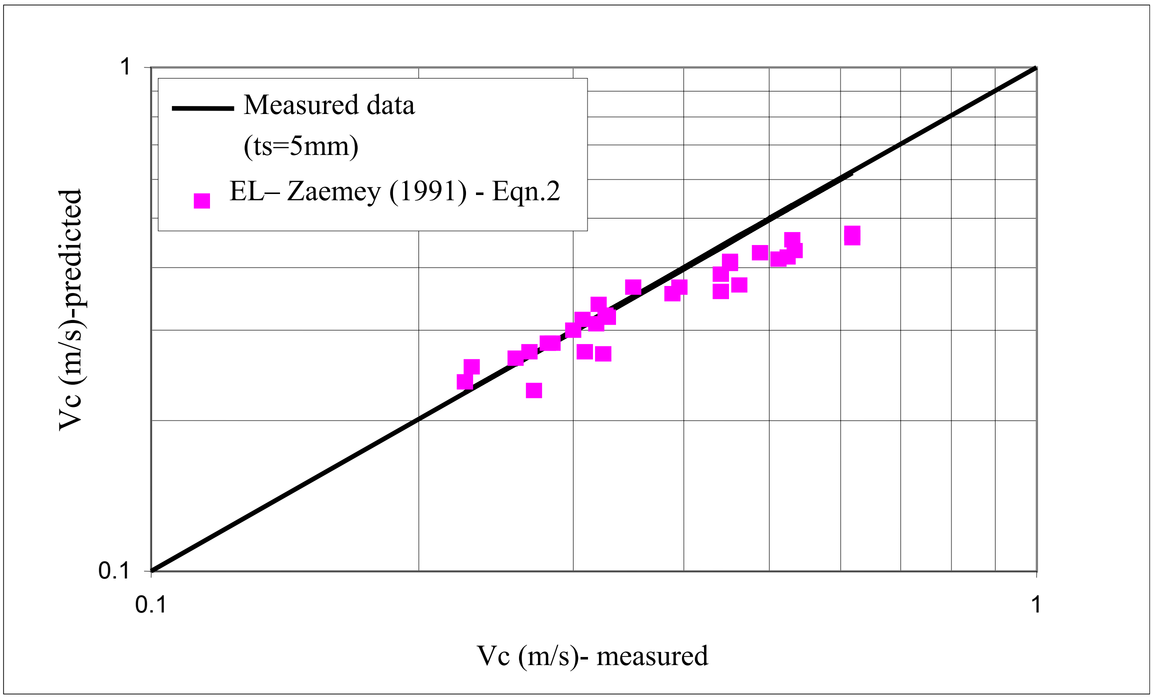


Fig.4. Comparison between the measured against the predicted critical velocity (El-Zaemy, 1991) – t_s = 5mm

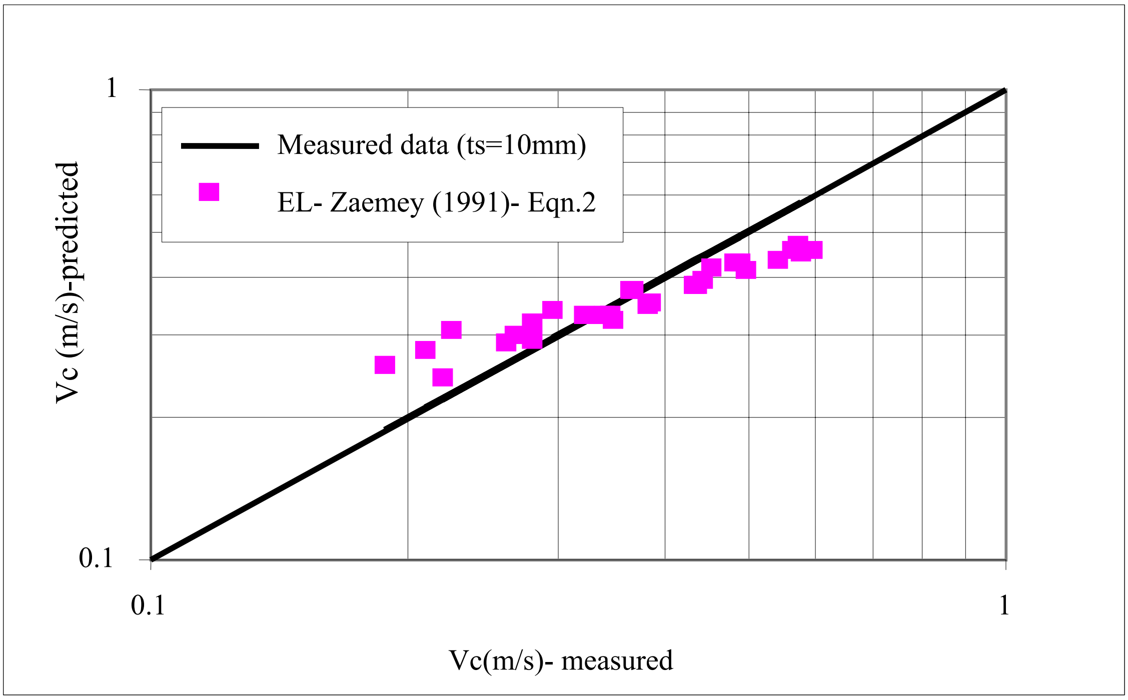


Fig.5. Comparison between the measured against the predicted critical velocity (El-Zaemy, 1991) – t_s = 10mm

The high values of r for equations (5) and (6) show that sediment bed thickness significantly affect the erosion of deposited loose beds in a rigid channel.

CONCLUSIONS

Evaluations of available incipient motion criteria show that they cannot take into account the effect of sediment bed thickness.

New equations with high values of r show the significance of including the bed thickness (t_s).

The new equations may be used to determine the thickness of sediment deposits which can be eroded by the existing storm drains. They can also be used to obtain the required slopes of the drains to ensure no permanent deposition of sediments over a period of time and rainfall events.

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