REATTACHED WALL JETS

BY N. RAJARATNAM * AND
D. MURALIDHAR **

Introduction

A number of hydraulic structures like sluices and sluice gates sometimes work under submerged flow conditions. The fluid streams issuing from such outlets could in general, be analysed as turbulent jets. If the confining boundaries are sufficiently far off from the outlet, the jet can be analysed as a free turbulent jet, about which extensive information is readily available [1]. If on the other hand, the jet occupies the full width of the channel and issues tangentially to its bed, then it could be treated as a turbulent wall jet [2, 3, 4, 5, 6].

If the full width jet enters the channel at a certain height above the bed, the flow pattern assumes very complex forms. As a first attempt, Rajaratnam and Subramanya [7] studied the diffusion of a full width jet issuing horizontally into the tailwater channel at a certain height above the bed with the drop being located at the nozzle outlet itself, as a restricted form of the reattached wall jet. Rajaratnam and Subramanya [8] also studied the diffusion of a jet produced by a sluice gate over a drop.

In this paper, the drop in the bed is located at a certain distance downstream of the nozzle, (see Fig. 1 *a*) so that the forward flow has the profile of a wall jet before the drop.

In Figure 1 *a*, a jet of depth of y_0 and an almost uniform velocity of U_0 enters the channel under conditions of deep submergence. Some distance after the end of the potential core, it grows as a fully developed plane turbulent wall jet. At the sudden drop, the wall jet curves down, towards the lower bed due to the creation of lower pressures (this phenomenon is known as the Coanda effect [9, 10]) and impinges on the bed at a certain section creating a zone of eddying flow of length L_e. The forward flow after some distance from this reattachment line (where the separated wall jet reattaches itself to the bed) grows as a wall jet which could be termed the reattached wall jet and an experimental study of the same is presented in this paper.

Experiments

The experimental arrangement was essentially the same as that used in the earlier studies [7, 8]. The velocity distribution in the forward flow was measured by means of a commercial 3 mm external diameter Prandtl-type Pitot-static tube. The bed shear stress τ_0 was measured by means of a Preston tube [11] of external diameter of 3 mm and an internal diameter of about 1.8 mm. The calibration curve used was that of Patel [12]. The reattachment line was found using a tuft probe. The pres-

* Associate Professor, Dept. of Civil Engineering, Univ. of Alberta, Edmonton, Canada.
** Research Associate, Dept. of Civil Engineering, Univ. of Alberta, Edmonton, Canada.

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Table 1 / *Experimental data*

Expt. No.	y_0 (in)	h (in)	U_0 ft/sec	$\frac{h}{y_0}$	L_e (in)	$\frac{L_e}{h}$	$\frac{L}{y_0}$	$R = \frac{U_0 y_0}{\upsilon}$
				FIRST SERIES				
1 A	1.00	1.69	7.27	1.69	4.50	2.66	12.50	5.27×10^4
1 B	1.00	1.69	9.75	1.69	4.75	2.81	12.50	7.07×10^4
2 A	1.00	3.08	8.84	3.08	7.75	2.52	12.50	6.41×10^4
2 B	1.00	3.08	7.14	3.08	7.50	2.44	12.50	5.18×10^4
3 A	1.00	5.14	8.55	5.14	11.50	2.24	12.50	6.19×10^4
4 A	1.50	3.29	7.80	2.19	8.25	2.50	12.50	8.46×10^4
5 A	1.25	3.25	9.11	2.60	8.40	2.58	12.50	8.25×10^4
				SECOND SERIES				
6 A	1.00	3.06	7.94	3.06	8.50	2.68	63.50	5.75×10^4
6 B	1.00	3.04	8.72	3.04	8.50	2.80	50.00	6.32×10^4
6 C	1.00	3.05	8.14	3.05	8.25	2.71	39.75	5.90×10^4
6 D	1.00	3.25	7.97	3.25	8.50	2.61	30.00	5.77×10^4
6 E	1.00	3.24	7.86	3.24	8.50	2.62	20.00	5.70×10^4

sure on the bed was observed by means of a large number of piezomoters located on the bed.

Two series of experiments were conducted. In the first series, the length before the drop L was kept equal to 12.5 y_0 and five sets of experiments were conducted with the height of the drop h varying from 1.69 to 5.14 times y_0. In the second series, keeping h/y_0 almost constant at about 3.0, L/y_0 was varied from 20 to 63.5. The important experimental results are given in Table 1. In all the experiments, the velocity distribution just before the drop was measured and the reattached wall jet was explored in great detail. Figure 2 is a typical example of the velocity distribution in the forward flow and Figure 3 gives the results of the bed shear stress for the first series. In Figures 2 and 3, x and $\bar{x}$ are respectively the longitudinal distances from the nozzle and the reattachment line and u is the turbulent mean velocity at a normal distance of y from the bed.

Analysis of Results

Length of the eddying region.

If L_e is the length of the eddying region, for large values of the Reynolds number:

$$R = \frac{U_0 y_0}{\upsilon}$$

it has been shown earlier [7, 9, 13, 14] that:

$$\frac{L_e}{h} = f\left[\frac{h}{y_0}\right] \quad (1)$$

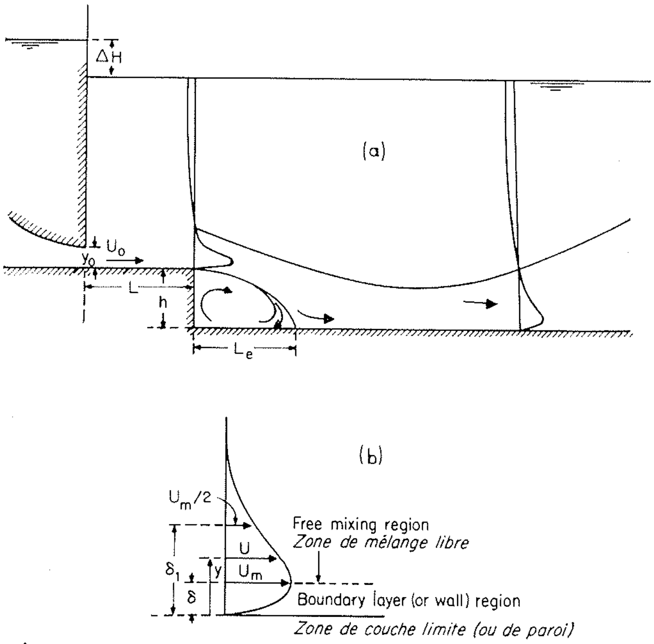
where υ is the coefficient of kinematic viscosity of the fluid. The variation of L_e/h with h/y_0 finalised in reference [7] is reproduced in Figure 4 along with the present results for the two series. The present results agree fairly well with this curve, thereby showing that L_e is not very much affected by the non-uniform velocity distribution just before the drop.

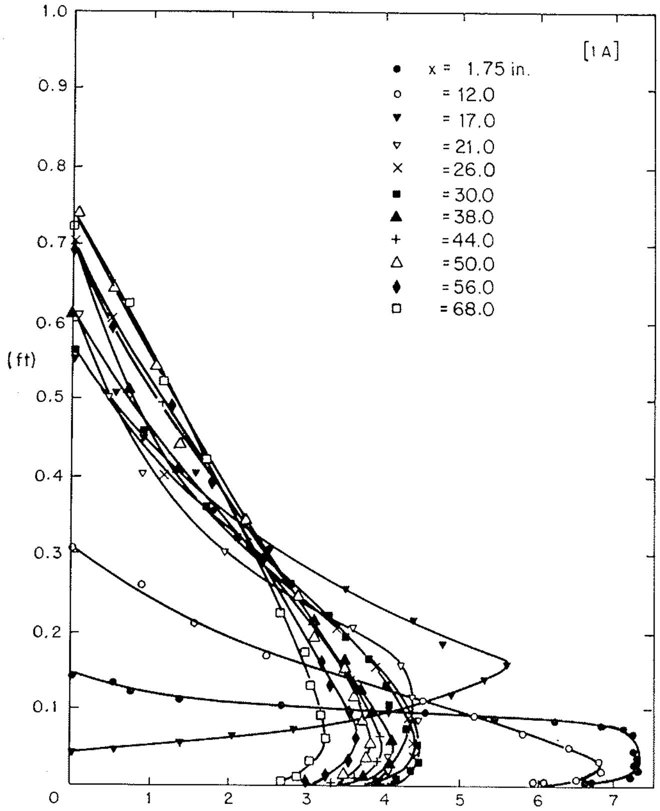
Reattached wall jet.

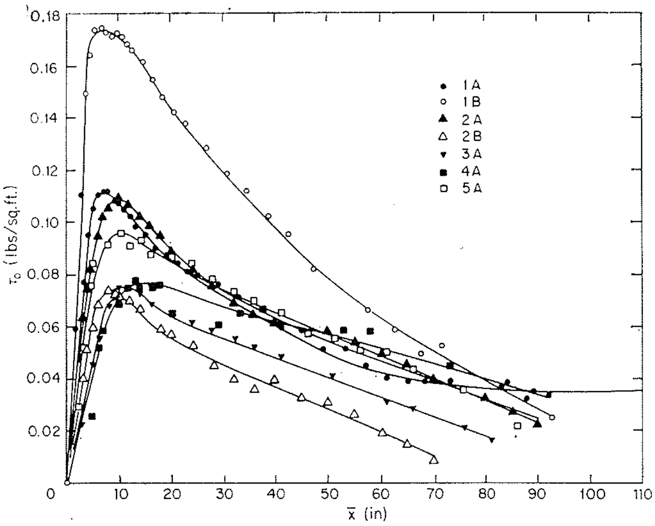
The velocity distribution measurement in the forward flow region after the reattachment line were tested for similarity by plotting the dimensionless velocity u/u_m against $\eta = y/\delta_1$, where u_m is the maximum velocity at that section, and δ_1 is the value of y at which $u = u_m/2$ and $\partial u/\partial y$ is negative (see Fig. 1 *b*). (u_m is generally called the velocity scale and δ_1 the length scale.) It was found that for both the series, after a distance of about 18 y_0 from the reattachment line, the velocity distribution is similar and agrees well that of the plane turbulent wall jet issuing into a stagnant surrounding on a smooth wall with zero pressure gradient, often referred to as the classical wall jet (CWJ). Figure 5 *a* shows a few typical plots of the first series and Figure 5 *b* shows a few typical plots of the second series.

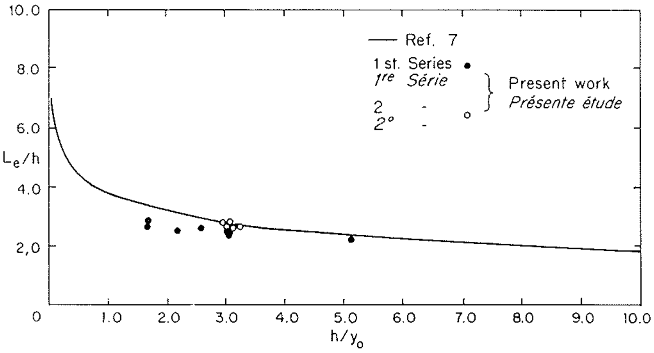
Velocity Scale.

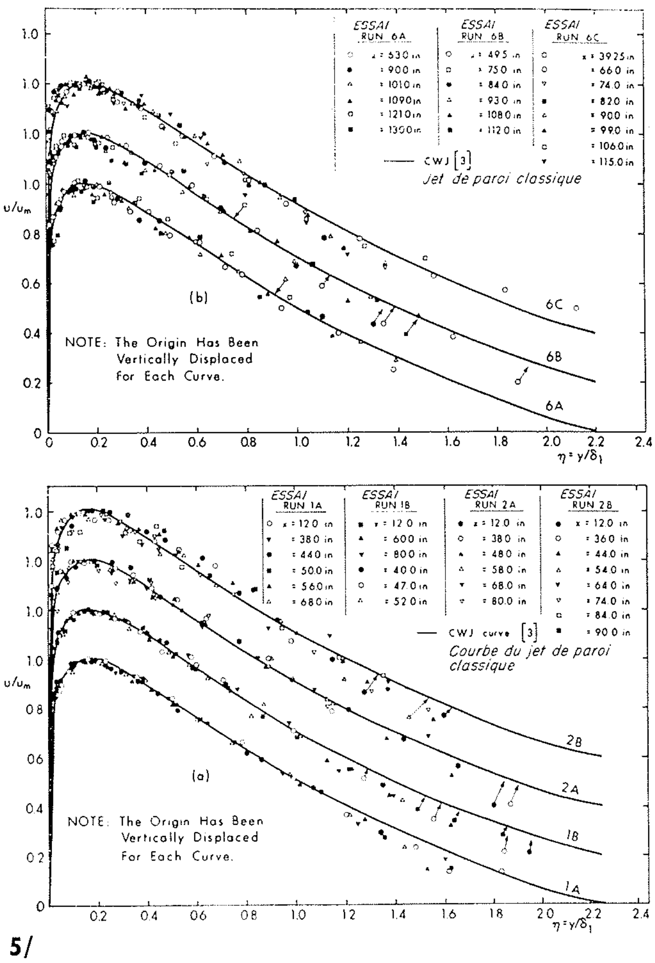
The variation of the dimensionless velocity scale (u_m/U_0) is studied in Figure 6 *a* for the first series and is compared with that of the classical wall jet [15]. It is seen that for any given value of h/y_0, after the drop, u_m is very small, increases slightly due to the favourable pressure gradient after the impingement region and then merges with the curve











1/ Definition sketch / *Schéma de définition.*

2/ Typical velocity distributions. (Note the change of origin for the first two sections.)
Répartitions-types des vitesses. (Noter le changement d'origine pour les deux premières sections.)

3/ Bed shear stress distributions.
Répartitions des efforts de cisaillement au fond.

4/ Lenght of eddying region.
Longueur de la zone tourbillonnaire.

5/ Velocity distribution. Reattached wall jet.
Répartition des vitesses. Jet de paroi rattaché.

of the classical wall jet. The curve for runs 1A and 1 B is shown by a dotted curve in Figure 6 *a*. The section at which u_m/U_0 variation merges with that of the classical wall jet curve is farther from the section at which the velocity distribution becomes similar.

The results for the second series are shown in Figure 6 *b* and they also show that after some distance, the velocity scale varies in the same manner as the classical wall jet.

Length scale.

The results of the dimensionless length scale δ_1/y_0 for the first series are shown plotted in Figure 7 *a*. It is seen that just before the drop, the length scale points fall on the CWJ curve [15] and in the region influenced by the drop the values are much higher. After some distance, the experimental curve merges with that of the CWJ curve. The curve for runs 1A and 1B is shown as a dotted line. The section at which merging with the corresponding CWJ curve takes place is farther away than the section at which merging takes place for the velocity scale. The magnitude of these distances is roughly of the same order as obtained by Rajaratnam and Subramanya [7]. The length scale results for the second series are shown in Figure 7 *b*. The same trend is noticable, but with more scatter.

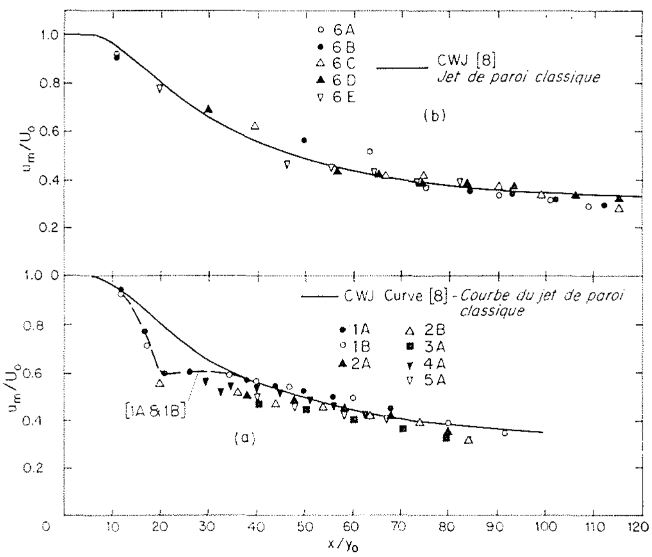
Bed shear stress.

Bed shear stress variations have been given earlier in Figure 3. Following the method used earlier by Rajaratnam and Subramanya [7, 8], these profiles were plotted with τ_0/τ_{0m} against $\bar{x}/\theta_1$, where τ_{0m} is the maximum value of τ_0 in any given run, θ_1 is the value of $\bar{x}$ at which $\tau_0 = \tau_{0m}/2$ and $d\tau_0/d\bar{x}$ is negative. Figure 8 *a* shows the results of the first series and Figure 8 *b* shows the results of the second series along with the similarity curve of Rajaratnam and Subramanya [7]. It is seen that the present results agree very well with the curve of reference [7] thereby showing that the shear stress distribution is not affected by the nature of the velocity distribution existing before the drop.

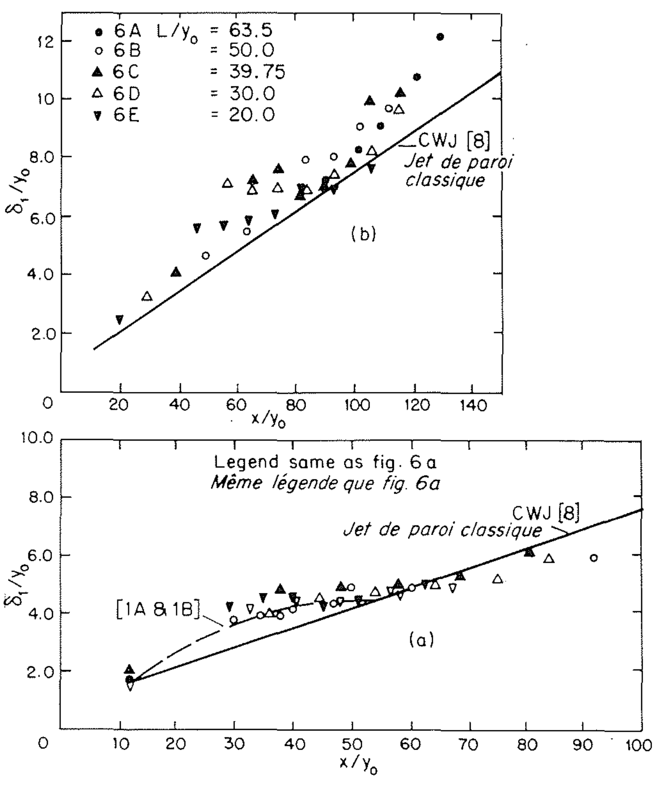
For the bed shear plot, the results of the dimensionless shear stress and length scales are shown in Figures 9 *a* and *b*. The present results for the shear stress scale are lower and higher for the length scale, when compared with the curves of Rajaratnam and Subramanya [7].

Conclusions

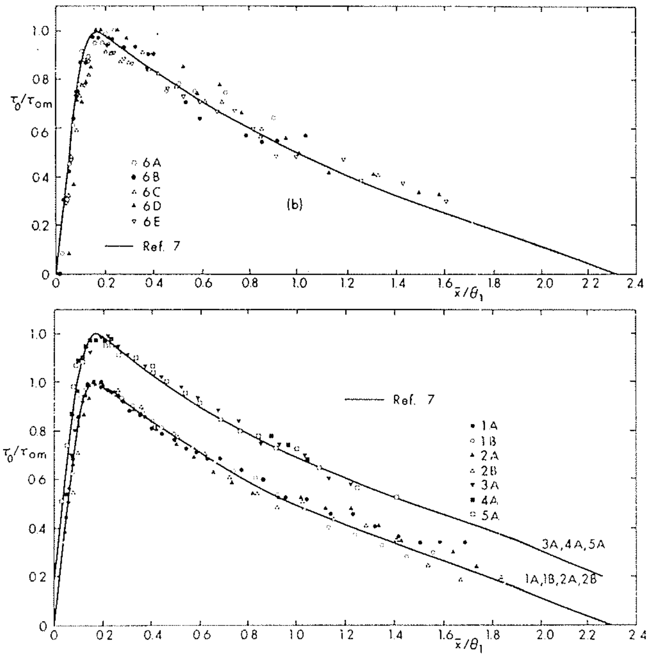
An experimental study has been made of the diffusion of submerged full width rectangular outlets, when there is a drop in the bed after some distance from the outlet. This could also be considered as a study of plane turbulent reattached wall jets. It has been found that the length of the eddying region below the drop is not affected appreciably by the nature of the velocity distribution existing before the drop. The velocity distribution in the reattached jet has been found to be similar, which agrees closely with that of the classical wall jet. The velocity and length scales merge with the variation of classical wall jet after certain distances from the reattachment line. A study has been made of the bed shear stress in the reattached flow.



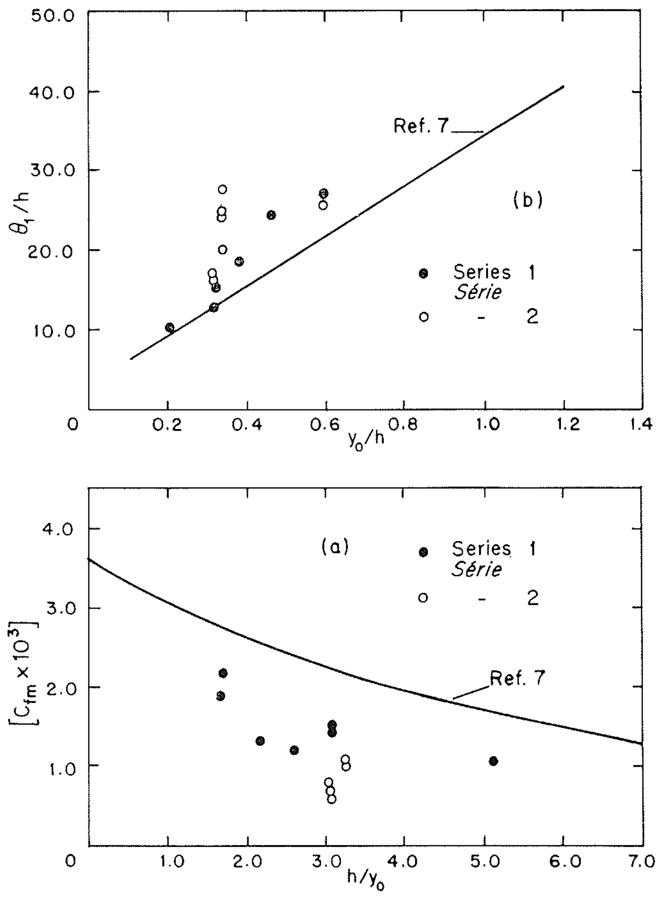
6/ Velocity scale.
Echelle des vitesses.



7/ Length scale.
Echelle des longueurs.



8/ Bed shear stress distribution.
Répartition des efforts de cisaillement au fond.



9/ Scales for the bed shear distribution.
Echelles de la répartition des efforts de cisaillement au fond.

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