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A STUDY OF THE TURBULENT FLOWS BEHIND A RECTANGULAR SHARP CRESTED WEIR IN OPEN CHANNEL USING LASER DOPPLER VELOCIMETRY

دراسة السريان المضطرب خلف الهدار المستطيل الحاد العتب في القنوات المفتوحة ثابتة العرض وذلك بإستخدام جهاز الليزر الحديث

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ملخص : يتناول البحث دراسة عملية لخصائص السريان المضطرب خلف الهدار المستطيل الحاد العتب في القنوات المفتوحة ثابتة العرض وذلك بإستخدام جهاز الليزر الحديث . ويهدف هذا البحث لدراسة عملية لكثافات الإضطراب والسرعات المتوسطة لإتجاه السريان والإتجاه الرأسي (Depthwise) عند قطاعات عرضية مختلفة خلف الهدار من بداية عتب الهدار وأخذت القياسات عند كل قطاعات من القاع وحتى سطح المياه في اتجاه العمق. ولدراسة دقيقة لخصائص السريان في منطقة القاع أخذت مسافات القياس كل ٥مم من القاع وحتى عمق ٧٠مم وباقي العمق تمت القياسات كل ١٥مم. وتمت الدراسة باستخدام ارتفاعات مختلفة للهدار وهى ١٥٠مم ، ٢٠٠مم. ولذلك تم دراسة تأثير الخشونة على كثافات الاضطراب وذلك بلصق رمل بقطر متوسط ٢مم على جسم الهدار وكذلك لمسافة ٢٠٠سم في القاع خلف الهدار. وقد تم اعداد منحنيات لابعدية لكثافات الإضطراب والسرعات في الإتجاهات المختلفة. وبتحليل القياسات العملية ومناقشة النتائج قد تبين أن كثافات الاضطراب عالية في القطاعات خلف الهدار وتقل تدريجيا بالبعد عن جسم الهدار وكذلك وجد أن الخشونة تزيد من كثافات الاضطراب. وبزيادة ارتفاع الهدار تزداد كثافات الاضطراب. وبهذه التقنية الحديثة (جهاز الليزر) تم قياس السرعة في اتجاه راسي ولم يتم قياسها بالأجهزة التقليدية وبغض النظر عن قيمتها الصغيرة إلا أن قياسها استنتاج جديد. وقد تبين أن السرعة في الاتجاه الرأسي صغيرة مقارنة بالسرعة في اتجاه السريان (Stremwise) وقيمتها تساوي صفر في أكثر من موقع في نفس القطاع في اتجاه عمق المياه ويتكرر ذلك في عدة قطاعات مختلفة خلف الهدار.

ABSTRACT:

This paper describes the experimental investigation using laser Doppler velocimetry (LDV) in the downstream of the rectangular sharp crested weir in a horizontal rectangular channel of constant width. The study was carried out for flows on smooth and rough weir. For precise and accurate measurements of mean and fluctuating flow characteristics such as streamwise and vertical turbulence intensity components and streamwise and vertical mean velocity components. The depthwise measurements were carried out for different heights of the weir along the centerline at different cross sections downstream of weir in the wake region. The results show that, the measured values of turbulence intensities are found to have high level of turbulence in the near wake region but are low in the far wake region. The turbulence intensities depict the occurrence of a constant turbulence close to the wall in the far wake region. The roughness was found to increase the turbulence. Also, it can be seen that with increasing weir height, the turbulence intensities are increased.

1- INTRODUCTION:

Flow fields associated with separation and reattachment have received significant attention because of their importance in many engineering applications. Examples include the flow behind the back ward-facing step, separated flow in diffusers, and separation bubbles on airfoils. Among these separation reattachment configuration, the flow behind rectangular sharp crested weir. To study the physics of flow separation behind the rectangular sharp crested weir, the simple geometry and the easily attainable two dimensionality of the test flow facilitate the analysis of separation induced flow

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phenomena, i.e. the determination of mean and fluctuating flow quantities such as streamwise and vertical components of turbulence intensity, and streamwise and vertical mean velocity components. A detailed review of the two-dimensional situations has been offered by Bradshaw and Wong [4] and later by Eaton and Johnston [7]. The reattachment length, one of the important properties because it indicates the rate of mixing of the separated shear layer, has been found by Eaton and Johnston [7] to be sensitive to many parameters, e.g., Reynolds number, background turbulence level, streamwise pressure gradient, etc. Near the reattachment region, the local turbulence intensity and Reynolds stresses reach their peak values, which can be attributed to the impingement of the unsteady shear layer on to step's floor. The coherent structures on the shear layer were studied recently by Bhattacharjee et al. [3] and Roos and Kegelman [12]. In a two-dimensional backward facing step, the instantaneous velocity traces indicate that the coherent structures in the shear layer are correlated almost across the entire span, Bhattacharrjee et al. [3]. Flow visualization by Cherdron et al. [5] showed vortex pair structures behind a sudden expansion inside a symmetric duct. In a channel with a fully developed velocity profile before the step, Armaly et al. [1] found multiple regions of separation downstream of the backward facing step on both the top and bottom sides of the channel walls. Their measurements showed that the appearance of a separation bubble on the wall opposite to the step destroyed the two-dimensionally of the flow, and wavy patterns of the spanwise separation-reattachment locations existed for both top and bottom separation bubbles. Their numerical results supported the existence of those additional separation regions. Several recent Navier-Stock computational work, Kim ad Monin [9] and Kaiktsis et al. [8]. A great number of detail studies, Ruck et al. [13], Nakagawa et al. [11], Etheidge et al. [6], and Amano et al. [2] have been published in the past on backward facing single sided step flows which describe the interactions of limiting geometrical parameters and flow characterizing quantities mostly in a time averaged version. Nashat [16] presented the model of vortex shedding for steady separated flow over a normal wall. Simulation of turbulent flow separation through closed rectangular conduit has been pointed by Nashat et al.[14]. The flow characteristics after a downward facing step in channel bed have been reported by Nashat al. [15]. The aim of the present research depicts the results of laser Doppler Velocimetry (LDV) investigation behind of rectangular sharp crested weir in a horizontal rectangular channel of constant width. Experiments are carried out on smooth and rough weir to study the turbulence intensity components, streamwise and vertical mean velocity and the effect of the roughness on the turbulence intensities.

2- EXPERIMENTAL SET UP AND TEST PROCEDURE

The measurements were carried out in a horizontal rectangular open channel that is 9500 mm long, 300 mm width and 500 mm height with glass wall 6 mm thick and a steel plate bed. Figure 1 depicts layout of the test facility. The water is supplied from a constant head overhead tank to the flume at a desired discharge that is continuously monitored with an on-line orifice meter. The flume side walls are made up of 6 mm thick glass sheets. A tail vertical gate is provided at the downstream end of the flume to maintain a required water depth of channel flow. The water is finally collected in a sump placed in the basement from where it is pumped back to the overhead tank by a 16 HP pump.

With reference to the origin fixed at the bed along the centerline, transverse of measuring volume was run to obtain the profiles of both the mean velocity components and RMS of turbulence intensities. The measuring points were closely spaced in the region of high velocity gradient. All the measurements were made for a constant discharge rate of 40 l/s on the free stream water depth of 320 mm. This gave Reynolds number based on the free stream velocity $4x10^4$ which ensured the turbulent flow for all the test conditions. Froude number of the free stream flow Fr = 0.230, ensured the free stream flow to be subcritical. To obtain the vertical profiles of the mean and fluctuating quantities, the measurements were conducted in the vertical plane along the centerline at different locations downstream the rectangular sharp crested weir. In the vertical direction along the depth, 30 measurements at 5 mm intervals up to 65 mm from the bed boundary and 15 mm for the rest were taken.

3- INSTRUMENTATION

The experimental data were collected using a DANTEC LDV system, consisted of a 5 watt-ion laser with two laser beams one blue (488 nm) and one green (514.5 nm), a Fiber-optic measuring probe in back-scater mode, two Burst Spectrum Analyzer (BSA) were used to evaluate the Doppler frequencies, and subsequent computer analysis consisted to velocity bias averaging and outlier rejection. Figure 2 shows a block diagram of the two component LDV set up used for the measurements. On a traverse bench, the measuring probe (laser beams or measuring volume) was focused at a measuring point from one side of the channel glass wall through an optical lens. The number of samples taken at every point was 5000 bursts. This correspond to a sample averaging time of about 100 seconds. The data rate was about 10-20 HZ. Before acquiring the data, the LDV signal was checked for its regular Doppler burst that correspond to a particle passing through the measuring volume. The measurements were taken at different positions downstream of the rectangular sharp crested weir for Q= 40 l/s. Figure 3 shows the location grid of the measuring sections (x/H) downstream the weir. The weir was fabricated from transparent prespex sheets, that is 260 mm and width 20mm thick. The height (H) of the weir was taken 150mm and 200mm.

3- RESULTS AND DISCUSSION:

(a)Streamwise Mean Velocity Distribution ($\bar{u}$ / U_o) along theDepth:

The values of u-component of streamwise mean velocity, made non-dimensional with respect to the streamwise free stream velocity U_o. Figure 5 depicts the profiles of streamwise mean velocity component $\bar{u}$ / U_o behind the rectangular sharp crested weir along the depth at different locations. The profiles of u/U_o along the longitudinal direction at the centerline exhibit the expected trends of flow separation, shear layer growth, and reattachment (reattachment occurs at x/H = 8±0.3). Directly downstream the weir, reversed flow and flow separation could be observed downstream the weir as shown in Fig. 5 at x/H= 1.0 as can be seen by the shape of the velocity profile and was observed by dye injection. These observation are consistent with the backstep flow measurement of Ruck and Mokida (1990).

(b) Vertical Mean Velocity Distribution ($\bar{v}/U_o$) along the Depth

The values of $\bar{v}$- component of vertical mean velocity, made mon- dimensional with respect to the streamwise free stream velocity U_o. Figure 6 depicts the profiles of dimensionless vertical mean velocity $\bar{v}/U_o$ behind the rectangular sharp crested along the depth at different locations at which streamwise mean velocities were measured. Although $\bar{v}/U_o$ fluctuates as one moves downstream of the weir, the magnitude decreases reaching relatively small value again at the farthest downstream of x/H =10. The zero magnitude of vertical component $\bar{v}/U_o$, occurs at more than one point at several locations. This observation is somewhat more intriguing as one may not expect more than one location at which $\bar{v}/U_o$ could be zero. One may attribute the multiplicity of null point to the three dimensional interaction between the entrance flow to the weir, almost with negative vertical velocity component, the influence of side wall weir itself along with horizontal bed impeding the downward component of velocity. This complex interaction would influence the flow pattern giving rise to multiplicity of null point.

(c) Streamwise Turbulence Intensities u'/U_o along the Depth:

Measurements were made for the two components of the fluctuating turbulence velocity (u` and v`) in terms of their root mean square (rms) values. However, because of the limitation of space, results for rms value of only the longitudinal component of turbulence fluctuations (u`) are presented for most cases. Root mean square (rms) of turbulence intensity made non-dimensional with respect to the free stream velocity U_o. Figure 7 depicts the profiles of streamwise component of dimensionless turbulence intensities u'/U_o with relative water depth y/y_o for different weir height of 150 and 200 mm at different locations behind the rectangular sharp crested weir for discharge 40 l/s. As a comprehensive observation, it is noted that the nature of distribution of the u'/U_o component of turbulence intensity is essentially the same for both heights. The turbulence u'/U_o of the weir height 200 mm is always stronger compared to the turbulence of the weir height 150 mm. A high level of turbulence in the near wake region (x/H = 1 and 2) results from the disturbance to the flow caused by the rectangular sharp crested weir, with the increasing distance from the boundary, the turbulence intensity u'/U_o increase in wall region defined by $y/y_o \leq 0.2$ tending towards a maximum in the intermediate region (core region) defined by $0.2 \leq y/y_o \leq 0.6$, turbulence intensity u'/U_o decease gradually in the upper region (free surface region) defined by $y/y_o > 0.6$, reaching the minimum at the free surface. Since turbulence intensity gradually decrease as we move towards the wall, instead of attaining its maximum value. At x/H= 5, the curve is more flattened and the u'/U_o component is partically constant in the central region (core region) of the flow. The maxima occurs very near the wall, indicating that the turbulence structure in the wall region is fully established. Also, Figure 8 depicts the variation of u'/U_o with y/y_o for rough and smooth weir. The roughness of the weir can be seen to cause higher level of turbulence throughout the flow region. Generally, the location of the minimum value of the turbulence intensity u'/U_o occurs at the free surface of the smooth and rough weir at all the cross sections. The behaviour of the vertical turbulence intensity component v'/U_o was found to be essentially the same as that of the

u'/U_o component, except that its magnitude was smaller than that for the longitudinal component u'/U_o.

5. CONCLUSIONS:

The experimental study on the turbulent flows behind a rectangular sharp crested weir in open channel indicates that:

The turbulence intensities have a high level of turbulence in the near-wake region, In the far-wake region the intensities are smaller and the profiles are similar in accordance with the fully developed flow. The roughness of the weir increases the intensity of turbulence. As a comprehensive observation, it is noted that, the minima of turbulence intensities being located in the upper region (free surface region) defined by $y/y_o > 0.6$, approximately at the free surface. In the near wake region at $x/H < 3.5$ a high level of turbulence results from the disturbance to the flow caused by the weir, maximum of turbulence occur in the core region (intermediate region) defined by $0.2 \leq y/y_o \leq 0.6$. At $x/H > 4.0$, the curve is move flattened, the maxima occurs very near the wall indicating that the turbulence structure in the wall region is fully established. The vertical mean velocity component $\bar{v}/U_o$ is observed to be small compared to the streamwise mean velocity $\bar{u}/U_o$. Regardless of its magnitude, measurement of the vertical velocity is a new finding using LDV technique. Although $\bar{v}/U_o$ fluctuates as one moves downstream of the weir, the magnitude gradually decreases reaching small value again at the farthest downstream. The depthwise variation of $\bar{u}/U_o$ component and the $\bar{v}/U_o$ component differ markedly, $\bar{v}/U_o$ may have multiple null points and positive as well as negative values. But $\bar{u}/U_o$ predominantly positive all along the depth except at the location nearer the wake region where it can assume negative or a zero value along the vertical axis. The general features of the afore described observations are consistent with those for backstep flows (Ruck and Mokiola, 1990) and (Nakagawa and Nezu, 1987).

6. NOMENCLATURE:

b	Channel width
Fr	Froude number
Q	Flow discharge
Re	Reynlds number
u	Streamwise mean velocity component in x/direction
u'	Streamwise turbulence intensity component in x/direction (RMS)
U_o	Streamwise mean free stream velocity (averaged over the cross section)
z	Spanwise distance along the channel width
$\bar{v}$	Vertical mean velocity component in y-direction
v	Vertical component of velocity fluctuation in y-direction (RMS)
x	Longitudinal axis along channel length
y	Transverse axis along channel height
y_o	Free stream water depth
H	Weir height
(RMS)	Root mean square
(LDV)	Laser Doppler Velocimetry

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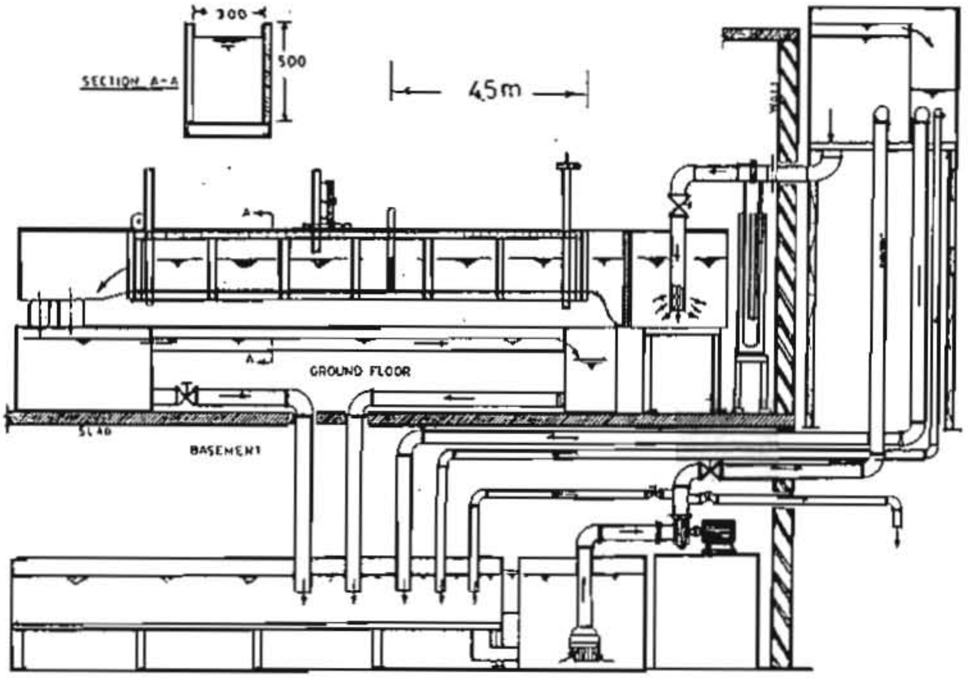


FIG. 1 SCHEMATIC OF TEST FACILITY

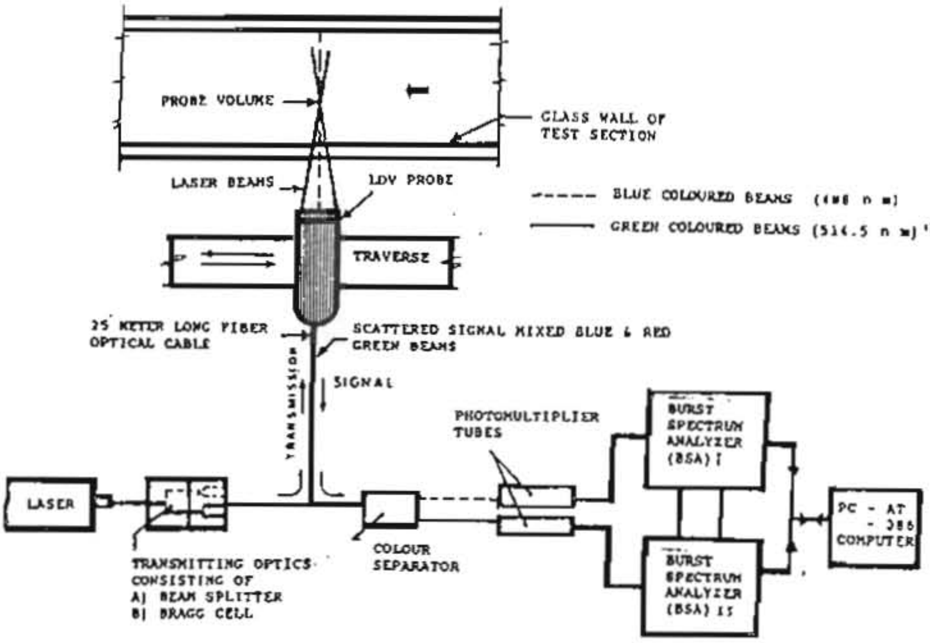


FIG. 2 : BLOCK DIAGRAM OF THE LASER DOPPLER VELOCIMETRY (LDV).

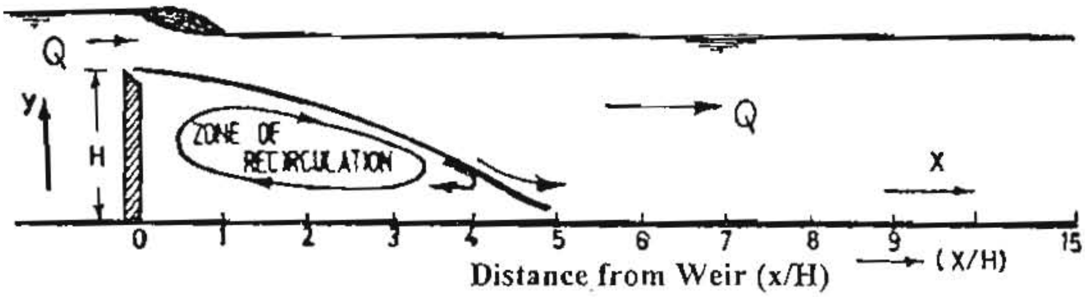
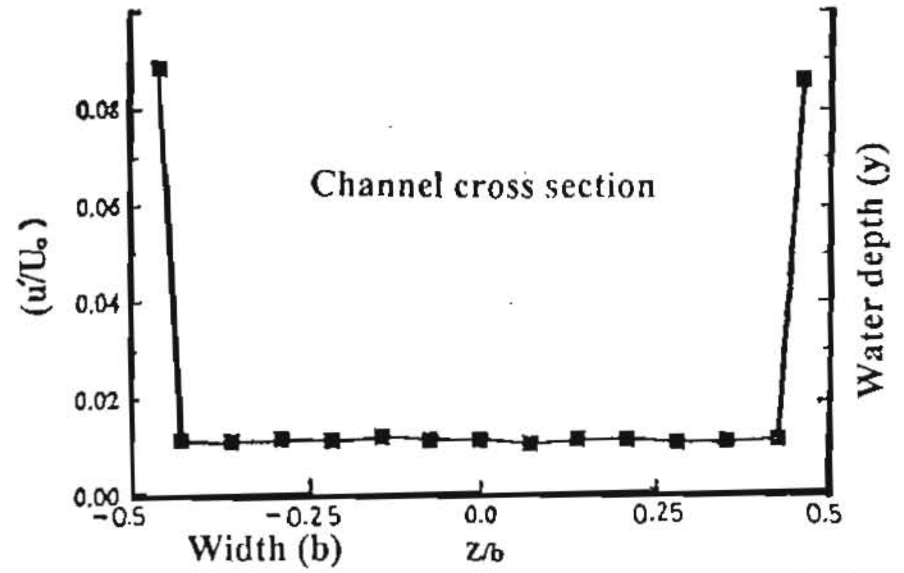
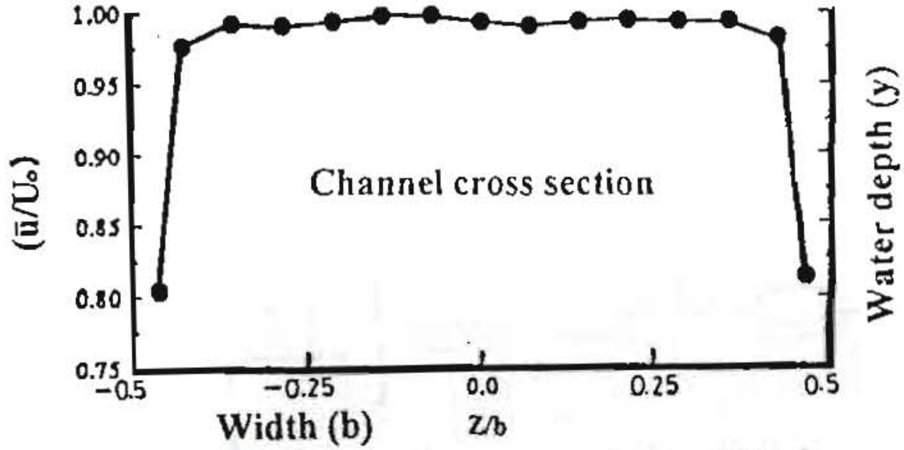


Fig. (3) Definition sketch of the rectangular sharp crested weir.



(b)Free streamwise turbulence intensity $(u'/U_\circ)$



(a) Free streamwise mean velocity $(\bar{u}/U_\circ)$

Fig. (4) Spanwise profiles of the free stream velocity and turbulence intensity.

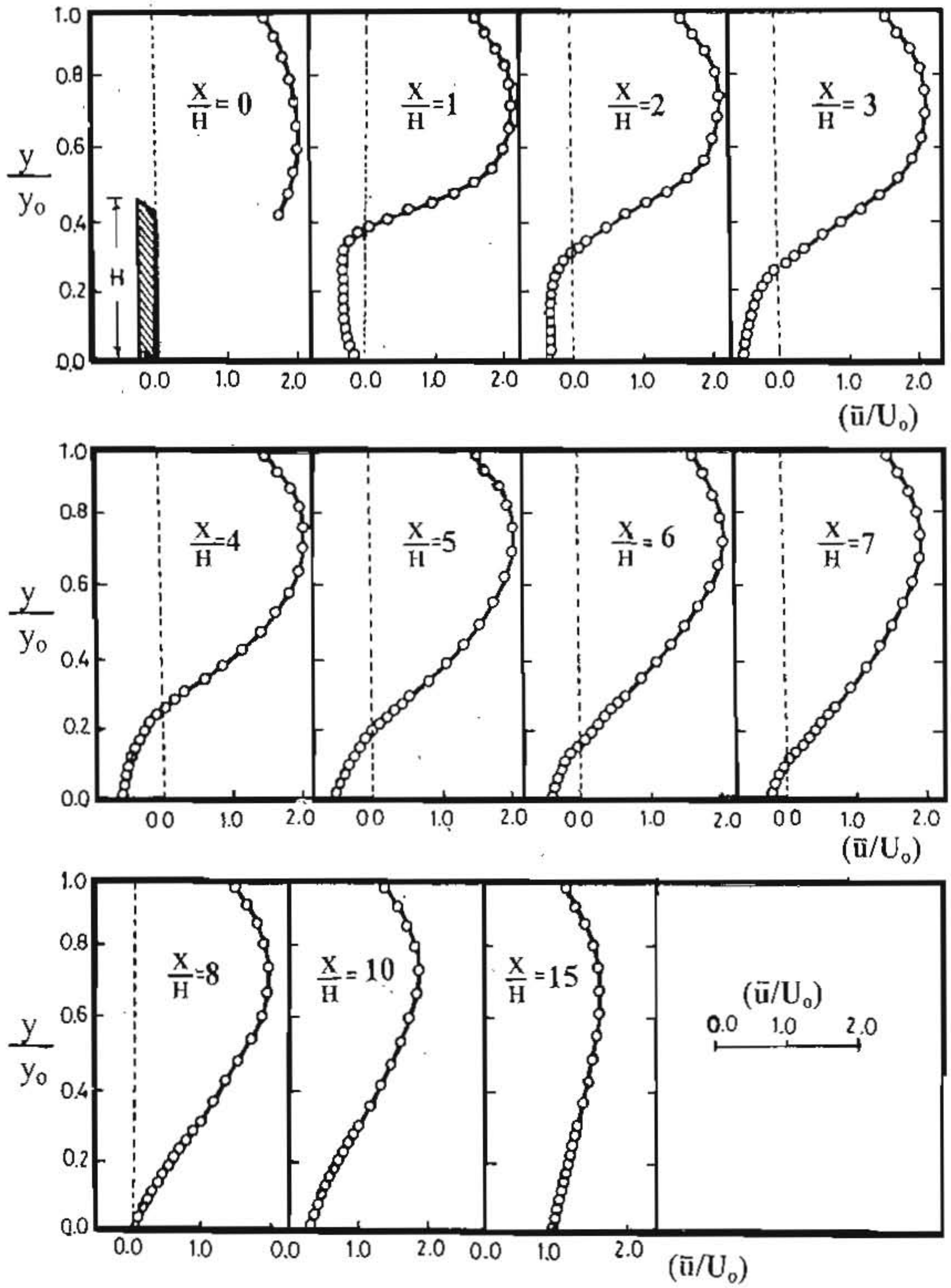


Fig. (5) Variation of streamwise mean velocity $\bar{u}/U_o$ with y/y_o downstream the rectangular sharp crested weir.

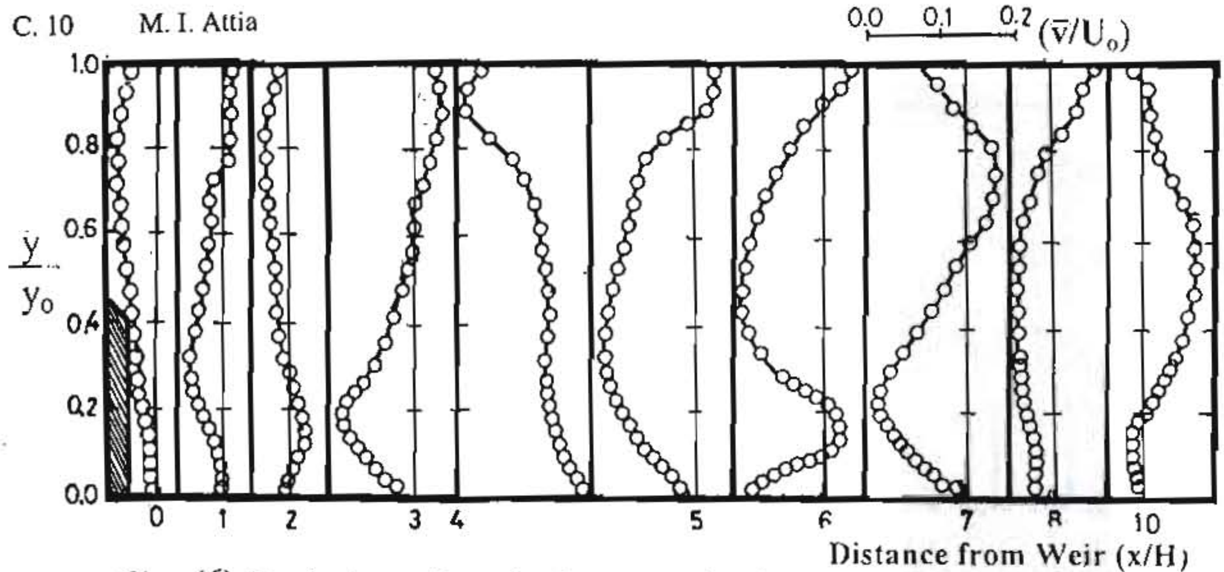


Fig. (6) Variation of vertical mean velocity $\bar{v}/U_o$ with y/y_o downstream the rectangular sharp crested weir

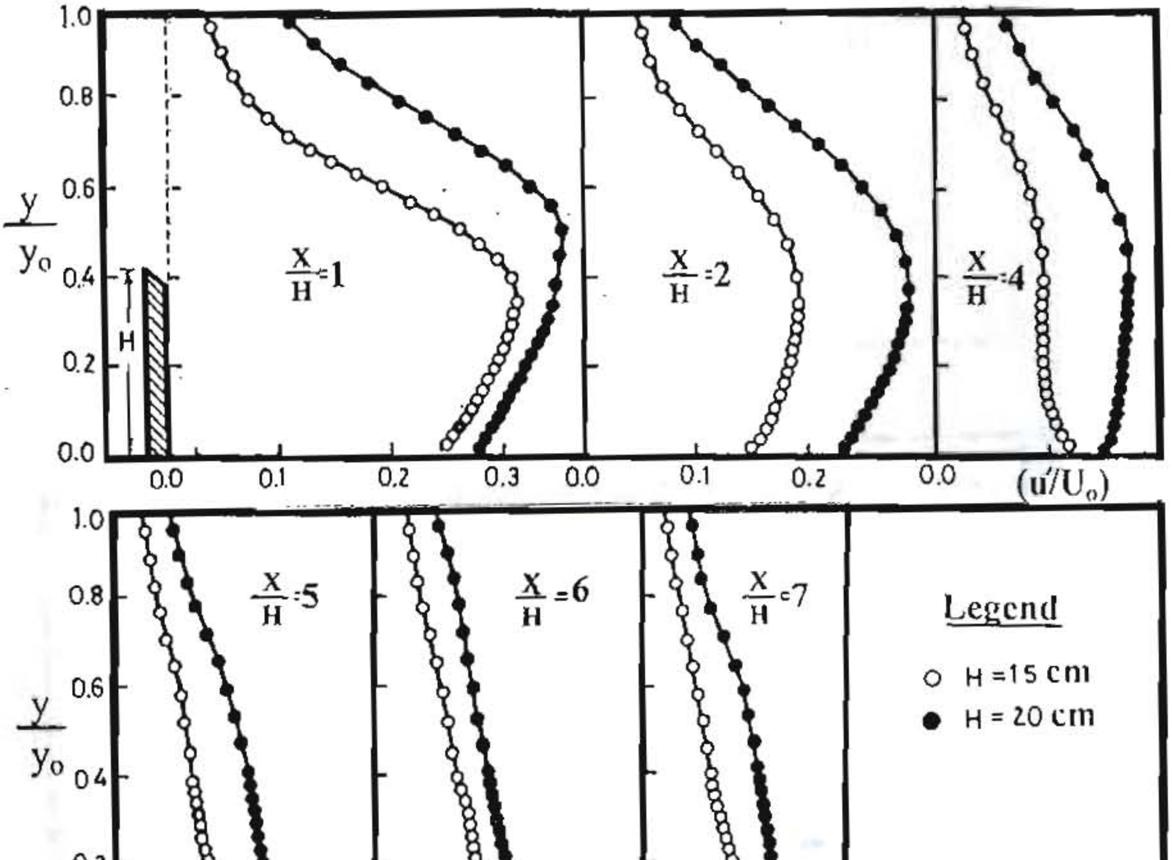


Fig. (7) Variation of stream wise turbulence intensity (u'/U_o) with y/y_o behind the sharp crested weir for different heights.

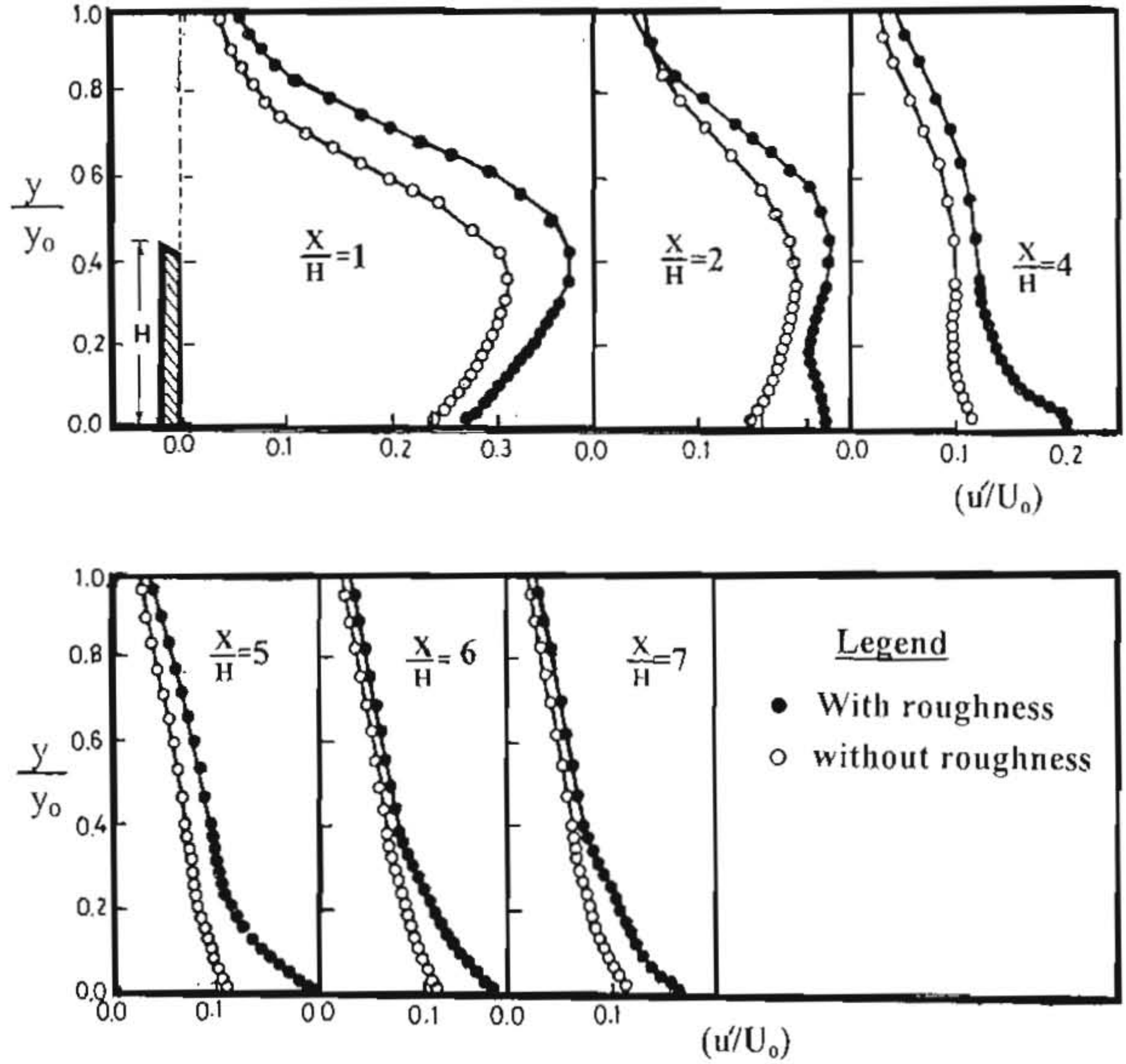


Fig. (8) Variation of streamwise turbulence intensity (u'/U_o) with y/y_o behind the rough sharp crested weir.