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EXPERIMENTAL STUDY OF THE INFLUENCE OF SILL ON THE MEAN AND TURBULENCE VELOCITIES IN OPEN CHANNEL FLOWS USING LASER DOPPLER VELOCIMETRY

دراسة معملية لتأثير الأعتاب على كثافات الاضطراب والسرعات للجريان فى القنوات المفتوحة

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ملخص- يقدم هذا البحث دراسة معملية لتأثير الأعتاب على السرعات وكثافات الاضطراب للجريان فى القنوات المفتوحة وذلك باستخدام جهاز الليزر الحديث. وقد تم دراسة كثافة الاضطراب وإجهاد قص الاضطراب (Turbulent shear stress) والسرعات المتوسطة في اتجاه السريان (Streamwise) والاتجاه الرأسى (فى اتجاه عمق المياه) عند قطاعات عرضية مختلفة أمام وفوق وخلف العتب وأخذت القياسات عند كل قطاع عرضى من القاع وحتى سطح المياه في اتجاه العمق ولدراسة دقيقة لكثافات الاضطراب وإجهاد قص الاضطراب والسرعات فى منطقة القاع أخذت مسافات القياس كل 5 مم من القاع وحتى عمق 70 مم والباقي من العمق تمت القياسات كل 15مم. وقد تم إعداد منحنيات لأبعدية لكثافات ومناقشة النتائج تبين أن كثافات الاضطراب فى اتجاه السريان دائماً أكبر من كثافات الاضطراب فى الاتجاه الرأسى. ووجد أن أقصى قيم لكثافات الاضطراب فى اتجاه السريان والاتجاه الرأسى حدثت فى نفس الموضع على المنحنيات عند كل قطاع عرضى مع تشابه المنحنيات لمركبات كثافات الاضطراب. وقد تبين كذلك أن كثافات ألاضطراب تزداد فى اتجاه إقتراب السريان من العتب وكذلك زادت فوق العتب وذلك بما يعادل أربع مرات لكثافات الاضطراب للسريان الحر بدون وجود العتب. وخلف العتب تزداد كذلك كثافات الاضطراب لأقصى قيم وفى اتجاه البعد عن العتب فى اتجاه الخلف تقل كثافات الاضطراب تدريجياً وقد تم قياس السرعة فى الاتجاه الرأسى ولا يمكن قياسها بأجهزة القياس التقليدية وبغض النظر عن قيمتها الصغيرة ولكن قياسها بهذه التقنية الحديثة استنتاج جديد وخصوصاً فى المنطقة أمام وفوق وخلف العتب وقد تبين أن السرعة فى الاتجاه الرأسى تساوى صفر فى أكثر من موقع فى نفس القطاع فى اتجاه العمق فى عدد من القطاعات خلف العتب مباشرة.

ABSTRACT:

This paper presents the results of a laser Doppler Velocimetry (LDV) investigation in the upstream, within and downstream of a sill in a horizontal rectangular channel of constant width. For precise and accurate measurements of the mean and fluctuating flow quantities such as streamwise and vertical turbulence intensity components u'/U_o and v'/U_o, streamwise and vertical mean velocity components $\bar{u}$ / and $\bar{v}/U_o$, and trubulent shear stress $u'v'/U_o^2$. The measurements are carried out along the depth at different cross sections upstream, above and downstream of a sill. The main objective of the present research is to conduct a comparative study of the depthwise variation of the streamwise and vertical turbulence intensity components, streamwise and vertical velocity components at different cross sections The results show that, the streamwise turbulence intensity is always greater compared to the vertical turbulence intensity, the trend of variation being similar. The maximum streamwise and vertical turbulence intensities u'/U_o and v'/U_o occur at the same location of the profiles. The turbulence intensities u'/U8 and v'/U_o increase, as the flow approaches the sill. Above the sill, the turbulence intensities levels are further enhanced, with the u'/U_o reaching a value of nearly four times the free stream value. Downstream the sill, as the flow approaches, the turbulence intensities u'/U_o and v'/U_o are much higher as compared to turbulence intensities upstream or above the sill.

1. INTRODUCTION:

If often occurs that in the control of rivers submerged sills are used to alter the flow. Sills can back the water up and thus divert the flow of the river into another channel during times of normal flow. In times of high flood, however, much of the flow can pass over the sills. In some Regulators and Barrages which are constructed in Egypt, the undergate sills are provided mainly for economical reasons

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as they decrease the height of gates and consequently their weights. However, the use of these sills represent some obstruction and constriction to the water flow which will induce a certain rise in the upstream water level increasing the heading up and thus contributing to excessive energy losses. The complex phenomena of flow over a bottom sill in an open channel has been studied. Such flows are important in the design of stilling basins, where they are used as a mean of stabilizing the hydraulic jump and for solving practical problems. The fluid motion resulting from the interaction of flow with a sill is theoretically and practically important. The hydraulic jump type stilling basins as they provide a useful mean for dissipating the excess kinetic energy downstream hydraulic structures have received a considerable attention of many scientists and engineers. The use of sills results in a drag force exerted on the sill and which depends on many independent variables such as the sill height and geometry, the location of the sill within the jump region, the spacing between the sills and the inflow conditions. These independent variables along with the high turbulent and non- uniform nature of the flow in the vicinity of the sill. The present research of the flow characterizes the influence of the sill on the turbulent flows in open channel. Much less information is available regarding the turbulence characteristics upstream, above and behind the sill in open channel flow. Numerous experimental studies have been conducted to understand the flow phenomena associated with flows past two dimensional ribs. Castro[4], Bergles and Athanassiadis [3], Antoniou and Bergeles [1], Durst and Rastorgi [5], Tropea and Gackstatter [13], Liou and Kao [8], and Phataraphruk and Logan [10] are representative of such studies. A number of numerical studies have also been performed in order to predict the flow behavior in flows past two-dimensional ribs. Typical numerical studies with the linear K-C model are, Durst and Rastogi [5], Benodekar et al. [2] and Leschziner and Rodi [7]. Using flow past a backward facing step, Thangam as Speziale [12] found that the nonlinear K-C model, that includes higher order terms representing nonisotropic effect. Improved predictions of separated flows past backseps using the linear K-C model have also been obtained by Speziale ad Ngo [11] and Thagam and Hur [12] Simulation of furbulent flow separation through closed rectangular conduit has been pointed by Nashat et al.[15] The flow characteristics after a downward facing step in channel bed have been reported by Nashat et al [16] Nashat [17] presented the model of vorter shedding for steady separated flow over a normal wall.

The present research deals with the experimental investigation by using Laser Doppler Velocimetry (LDV) to measure the streamwise and vertical turbulence intensity components, streamwise and vertical velocity components, and turbulent shear stresses in a horizontal rectangular channel flume of a constant width. The measurements were carried out using LDV a non-intrusive Fibre Optic state of the art technique, in the upstream, within and behind of sill at different cross sections across and along the channel axis for specific maximum discharge of 401/S. The main objectives of the present research are: (1) To use the LDV, which includes the data acquisition system, data processing to measure mean and fluctuating flow quantities at different locations upstream, above and behind the sill in open channel flow, (2) To conduct a comparative study of the depthwise variation of streamwise and vertical turbulence intensity components at different cross sections upstream, above, and behind the sill at different cross section, (3) To make a comparative study of the depthwise variation of streamwise and vertical velocity components upstream, within and downstream the sill at different locations, and (4) To make a comparative study of the turbulent shear stress upstream, above and behind the sill at different cross sections.

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. The sill was fabricated from transparent prespex sheets.

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 1/s at a free stream water depth of 320 mm. This gave Reynolds number based on the free stream velocity 4×10^4 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 upstream, above and behind the sill. 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. The height (H) of the sill was kept at 90 mm.

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 sample 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 upstream, above and behind of the sill, for Q =40 l/s. Figure 3 shows the location grid of the measuring section (x/H) upstream, above and behind the sill.

4. RESULTS AND DISCUSSION:

Root mean square (RMS) values of streamwise and vertical component of turbulence intensities u\` and v\` are made non-dimensional with respect to the streamwise mean free stream velocity U_o. The water depth is non-dimensionalized by the free stream water depth y_o. Turbulence at the wall construed to be turbulence at a very location from the wall of the order of 5 mm as observed in LDV experimentation, and not at the wall itself perse. It may be mentioned here that the minimum distance away from the boundary at which the turbulence and velocity measurements commenced was 5 mm. At the boundary velocity and turbulence are zero. The two-dimensionality of the stream flow was examined by measuring the spanwise distribution of the streamwise velocity components. As demonstrated by the mean velocity and turbulence intensity profiles in figure 4 (a) and (b).

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

Figure 5 depicts the profiles of streamwise mean velocity distribution u/U_o upstream, above and behind the sill along the depth for Q =40 l/s at different locations. The streamwise mean velocity profile along the longitudinal direction at the centerline indicates gradual increase from upstream alone up to the entrance of the downstream zone of the sill. Subsequently, the magnitude decreases gradually downstream. It is seen that the measurements at x/H =-2 indicate flow separation upstream of the sill. Directly above the sill, the measured velocity profiles at x/H = -1 an x/H = 0.0 indicate a small separation region blanketing the sill surface and a shear layer profile above it. Downstream the sill, the profiles exhibit the expected trends of flow separation, shear layer growth, and reattachment (reattachment occurs at x/H = 5 $\pm$ 0.4). At the downstream corner locations of the sill, reversed flow and flow separation could be observed downstream of the sill as shown in Figure 5 at x/H = 1.0 as can be seen by the shape of the velocity profile and was observed by dye injection. Reversed flow was also observed at the beginning of the sill. These observations are consistent with the backstep flow measurements of Chandrsuda and Bradshaw (1981).

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

Cross-stream velocities are exhibited in Figure 6 depicts the profile of vertical mean velocity $\bar{v}/U_o$ of the sill at the same flow conditions and locations at which the streamwise mean velocities were measured. Upstream of the sill and above it, the measurements reveal a strong positive vertical velocity component $\bar{v}/U_o$ and a curved flow deflected upward by the sill. Downstream of the sill, at x/H =1 and 2, the positive velocities below y/y_o = 0.25 represent the separated eddy behind the sill, while the positive velocities above y/y_o = 0.25 represent the effect of the upward deflection of the flow by the sill. Difference in the $\bar{u}/U_o$ and $\bar{v}/U_o$ profiles is the marked changes in the magnitude along the depth. In $\bar{u}/U_o$ profile, changes were relatively smooth, with smaller number of points of contraflexure, while $\bar{v}/U_o$ assumes both positive and negative values at the same section and hence the zero value also at some intermediate locations. The nature of variation, viz., change from positive to negative magnitude and vice-versa occurred at different sections. However, in the profile of u/U_o such a variation occurred near the separation zone due to reversal of flow. The zero magnitude of vertical velocity component $\bar{v}/U_o$ occurs at more than one point at different locations. This observations is somewhat more intriguing as one may not expect more than one location at which v/U_o could be zero.

c) Streamwise Turbulence Intensities u`/Uo along the Depth:

The streamwise turbulence intensity u'/U_o with relative water depth y/y_o, results are shown in Figure 7. Generally, maximum streamwise and vertical components of turbulence intensities u'/U_o and v'/U_o, and turbulent shear stress $\overline{u'v'}/Uo^2$ occur at the same location approximately at y/y_o = 0.2 as shown in Figures 7,8 and 9. As a comprehensive observation, it is noted that the streamwise turbulence intensity u'/U_o is always stronger compared to the vertical turbulence intensity v'/U_o. Clearly, in the vicinity of the separated upstream of the sill, the measured turbulence levels are substantially higher than in the free stream, with the near-wall, about 2.5 times the free stream values. The upward deflection of the flow by the sill leads to higher velocity gradients and thus to a higher production of turbulence. Directly above the sill, the measured turbulence levels are further enhanced, with the streamwise intensity reaching a value of nearly four times the free stream value. This increase in the peak intensity is significant and noteworthy. It can be explained by noting that along y/y_o = 0.2, as the flow approaches the sill, the no-slip constraint along the sill face leads to high values of du /dx and du / dy. Since the production of turbulence is proportional to du/dx and du/dy, the turbulence levels are significantly enhanced in the region directly above the sill. Downstream of the sill, as the flow separates, the peak values decay, and the locus of the peak droops downward with the shear layer toward reattachment. Just downstream of separation ($x/H \leq 3$), the profiles show a sharp peak in the shear layer and a flat profile in the recirculation region. With increasing x/H, the turbulence is diffused; the profiles become more uniform; and the peak turbulence level decays. The general features of the aforedescribed observations are consistent with those for backstep flows (Chandrsuda and Bradshaw, 1981) and a flow through a pair of sills (Liou and Kao, 1988). However, in these studies, the intensities increase in the initial part of the separated shear layer, but in the present measurements, the maximum streamwise turbulence intensity occurs directly above the sill.

d) Vertical Turbulence Intensities v'/Uo along the Depth:

The cross-stream turbulence intensity v'/U_o with relative water depth y/y_o profiles are shown in figure 8. First, it is observed that the measured cross-stream intensities v'/U_o are significantly smaller than the measured streamwise turbulence intensities, particularly in the near-sill region ($-2 < x/H < 3$), indicating the no isotropic nature of the separated shear layer. Downstream of reattachment ($x/H > 5$), the cross-stream and streamwise intensities become more comparable, with the respective peaks at $x/H = 6$.

e) Turbulent Shear Stress $u'v'/U_o^2$ along the Depth:

Turbulent shear stress results $v'u'/U_o^2$ with relative water depth y/y_o are presented in Figure 9. The measure values of turbulent shear stress are consistent with the trends for cross stream turbulence intensity v'/U_o, i.e., the shear stress peaks downstream of the separation, as observed for backstep flows. In the recirculation region, $x/H = 1.0$ and 2.0, the $u'v'/U_o^2$ values are small, but with increasing x/H, both convection and diffusion lead to more uniform profiles.

5. CONCLUSIONS:

The experimental study on the influence of sill on the mean and turbulence velocities in open channel flows indicates that:

As a comprehensive observation, it is noticed that, the streamwise turbulence intensity u'/U_o is always greater compared to the vertical turbulence intensity v'/U_o, the trend of variation being similar. The maximum streamwise and vertical turbulence intensities u'/U_o and v'/U_o occur at the same location of the profiles. The turbulence intensities u'/U_o and v'/U_o increase, as the flow approaches the sill. In the vicinity of the separation upstream of the sill, the measured u'/U_o levels are substantially higher than in the free steam about 3.0 times. Above the sill, the turbulence intensities u'/U_o and v'/U_o levels are further enhanced, with the u'/U_o reaching a value of nearly four times the free-stream value. Downstream of the sill, as the flow approaches, the turbulence intensities u'/U_o and v'/U_o are much higher as compare to turbulence upstream or above the sill, the peak values decay, and the locus of the peak droops downward with the shear layer toward reattachment. Just downstream of separation $x/H < 3.0$, the profiles show a sharp peak in the shear layer. With increasing x/H, the turbulence is diffused; the profiles become more uniform; and the peak turbulence levels decays. It is seen that, from the streamwise mean velocity profiles $\bar{u}/U_o$, indicate flow separation upstream of the sill. Above the sill, velocity profiles $\bar{u}/U_o$ indicate a small separation region blanketing the sill surface and a shear layer above it. Downstream of the sill, the profiles of $\bar{u}/U_o$ exhibit the expected trends of flow separation, shear layer growth and reattachment occurs at x/H =(5 +0.4). Clearly, from the cross-stream velocities $\bar{v}/U_o$ profiles, upstream the sill and above it the results reveal a strong positive $\bar{v}/U_o$ component and a curved flow deflected upward by the sill. Downstream of the sill, the positive velocities $\bar{v}/U_o$ below $y/\ y_o = 0.2$ represent the separated eddy behind the sill, while the positive velocities above $y/y_o = 0.2$ represent the effect of the upward deflection of the flow by the sill. The general features of the foredescribed observations are consistent with those for backstep flows (Chandrsuda and Bradshaw, 1981) and a flow through a pair of ribs (Liou ad Kao, 1988).

6.NOMENCLATURE

b	Channel width
Fr	Froude number
Q	Flow discharge
Re	Reynlds number
$\bar{u}$	Streamwise mean velocity component in x/direction
u`	Streamwise fluctuating velocity 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′	Verical fluctuating velocity component in y/direction (RMS)
x	Longitudinal axis along channel length
y	Transverse axis along channel height
y_o	Free stream water depth
H	Sill height
(RMS)	Root mean square
(LDV)	Laser Doppler fluctuating velocity

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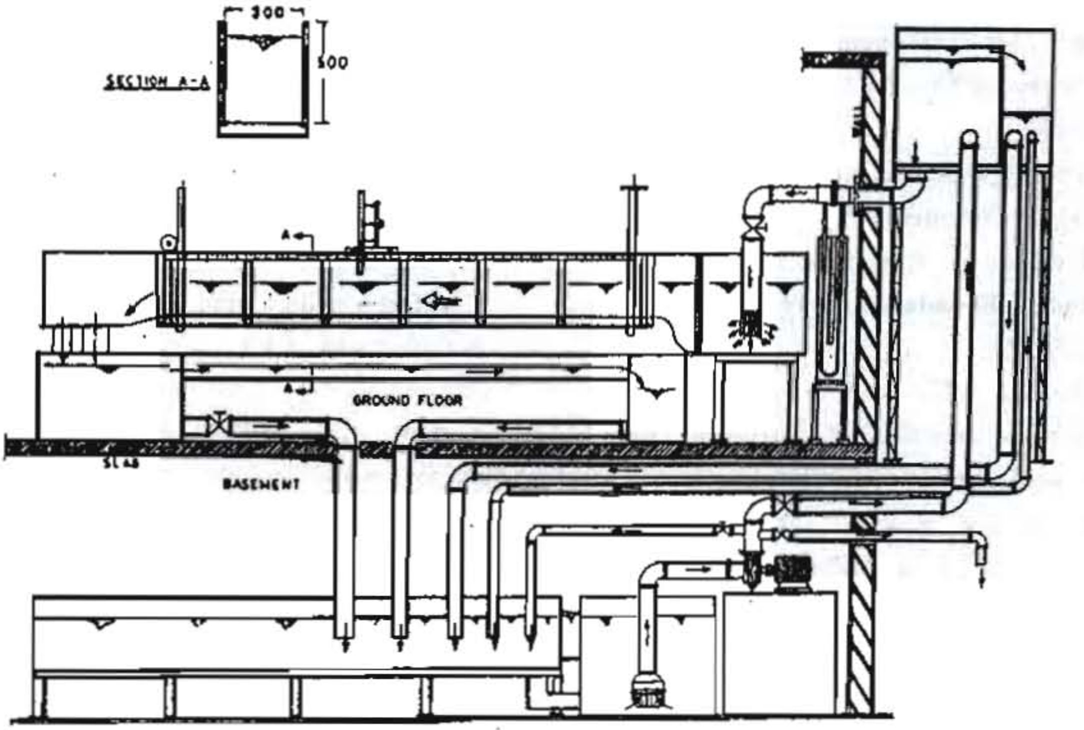

FIG.1 SCHEMATIC OF TEST FACILITY

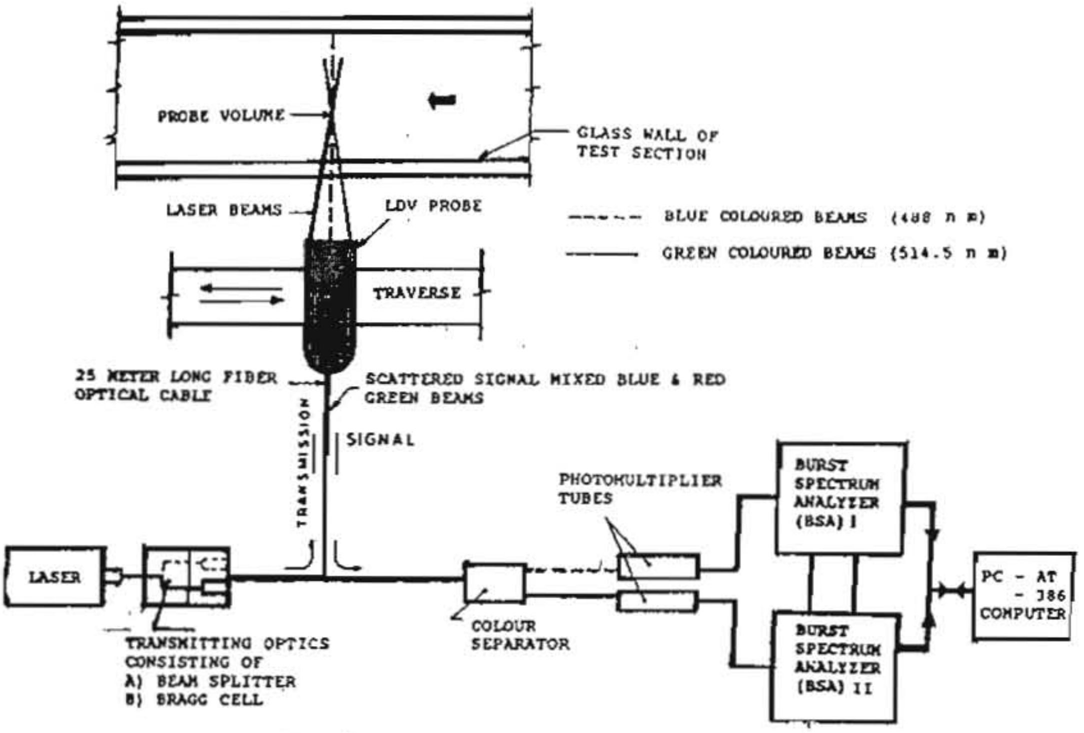

FIG. 2 : BLOCK DIAGRAM OF THE LASER DOPPLER VELOCIMETRY (LDV).

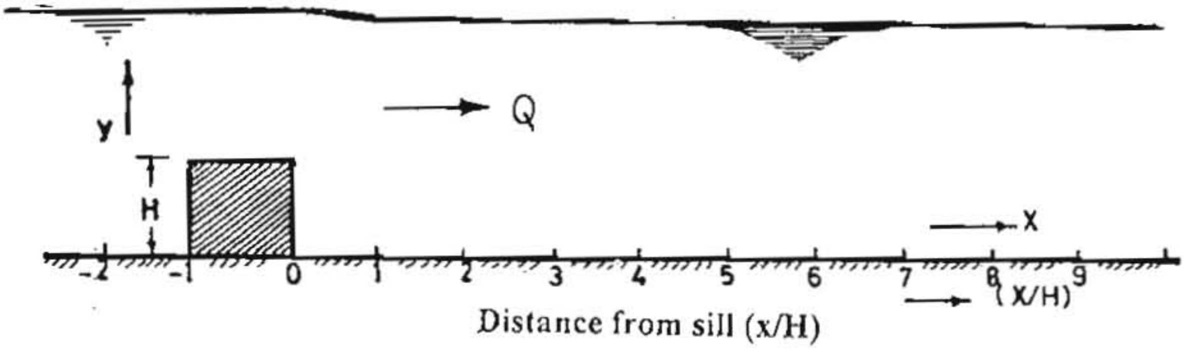

Fig. (3) Definition sketch of the sill.

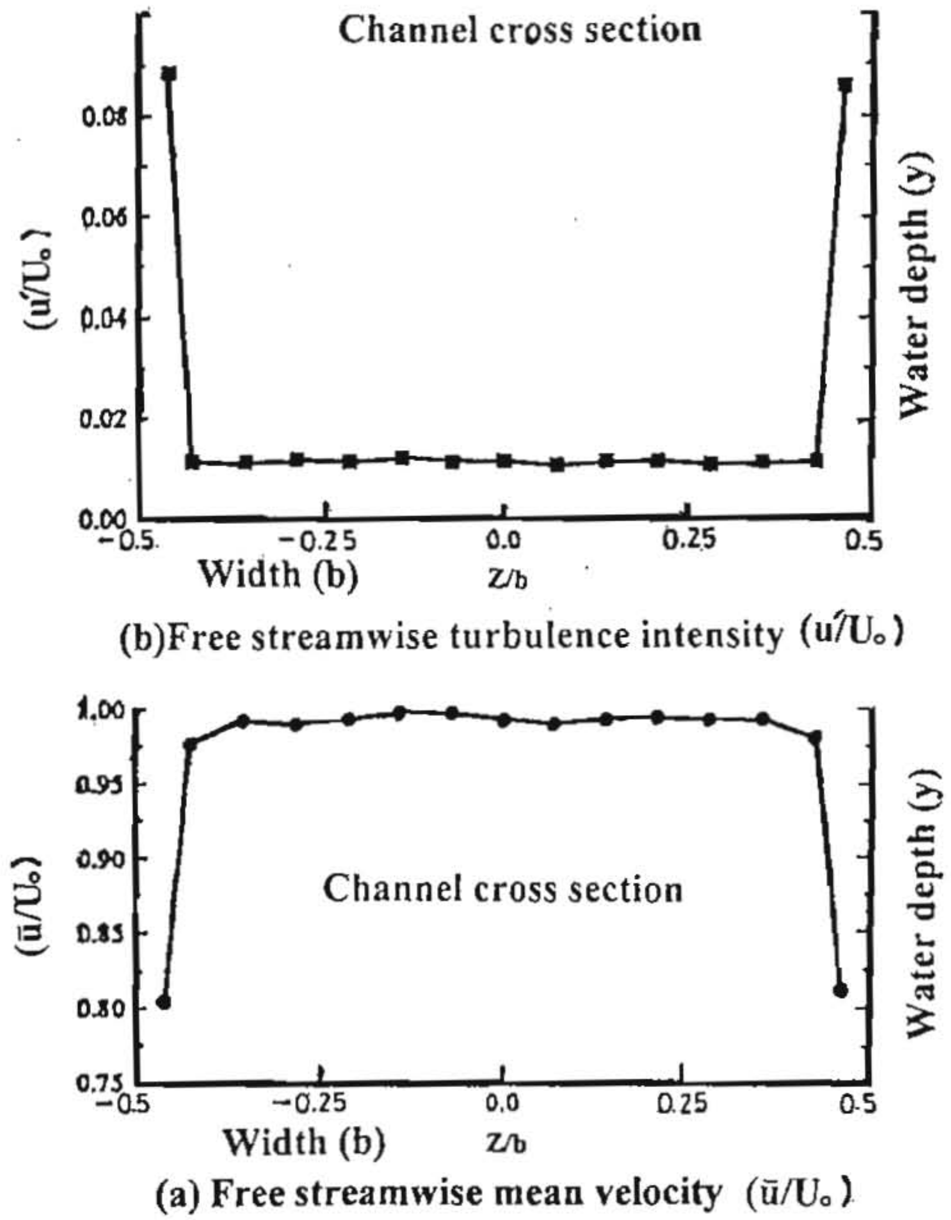

Fig. (4) Spanwise profiles of the free stream velocity and turbulence intensity.

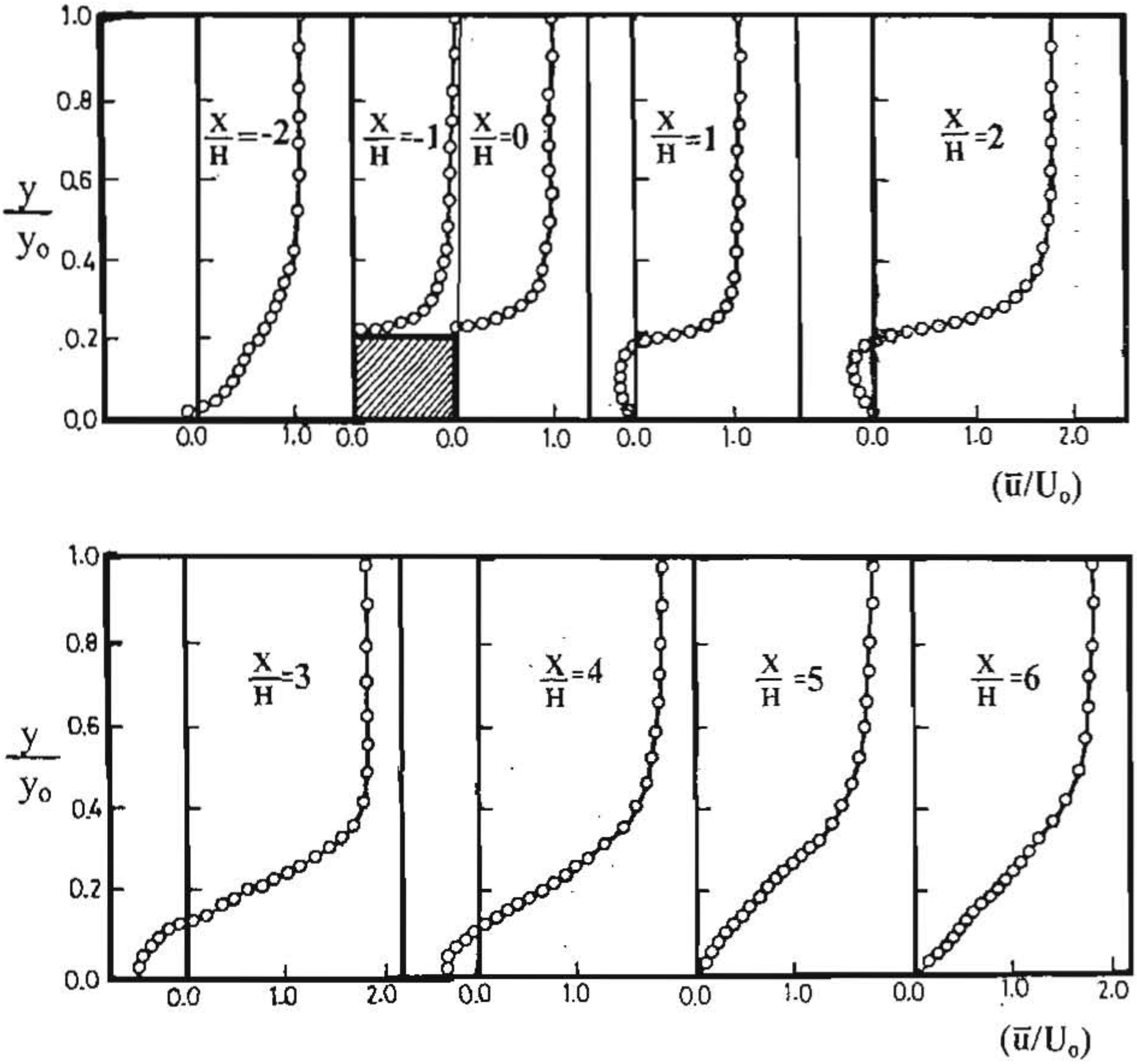

Fig. (5) Variation of streamwise mean velocity $\bar{u}/U_o$ with y/y_o upstream, above and downstream the sill.

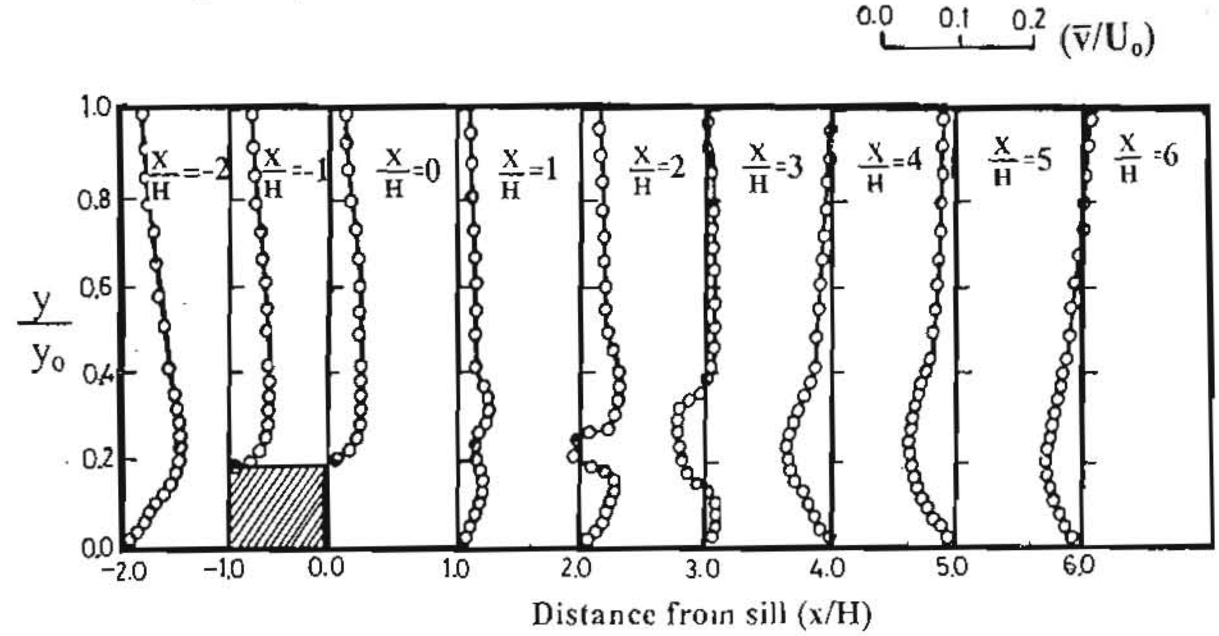

Fig. (6) Variation of vertical mean velocity $\overline{v}/U_o$ with y/y_o upstream, above and downstream the sill.

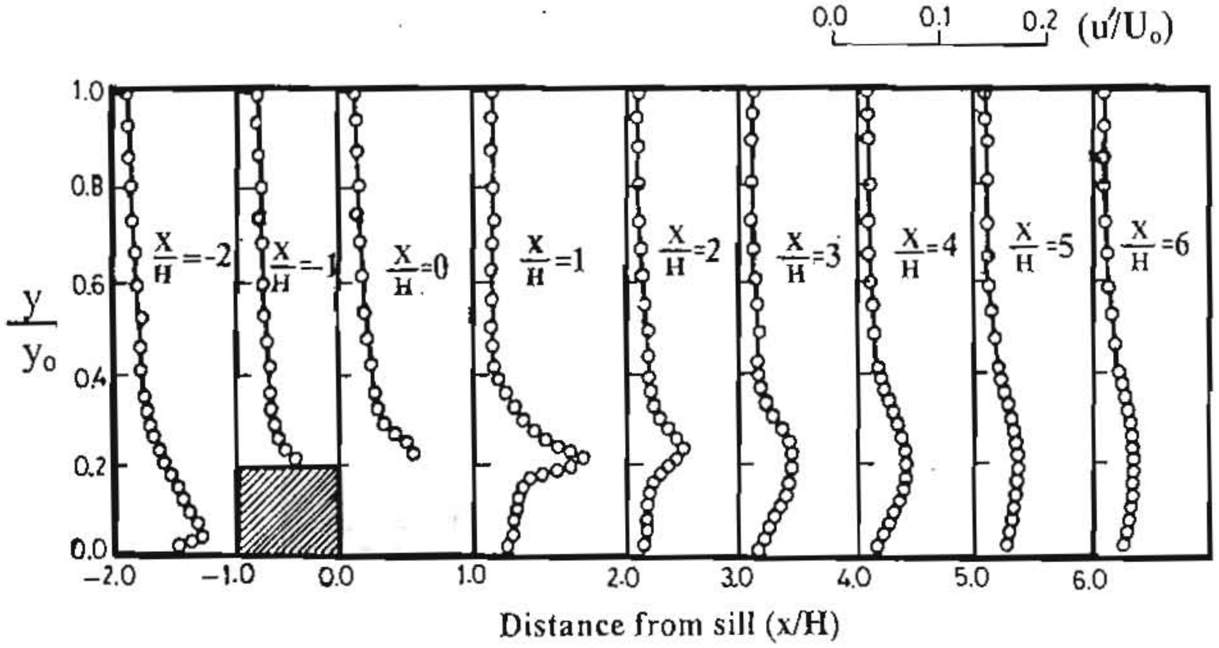

Fig. (7) Variation of of streamwise turbulence intensity (u'/U_o) with y/y_o upstream, above and downstream the sill.

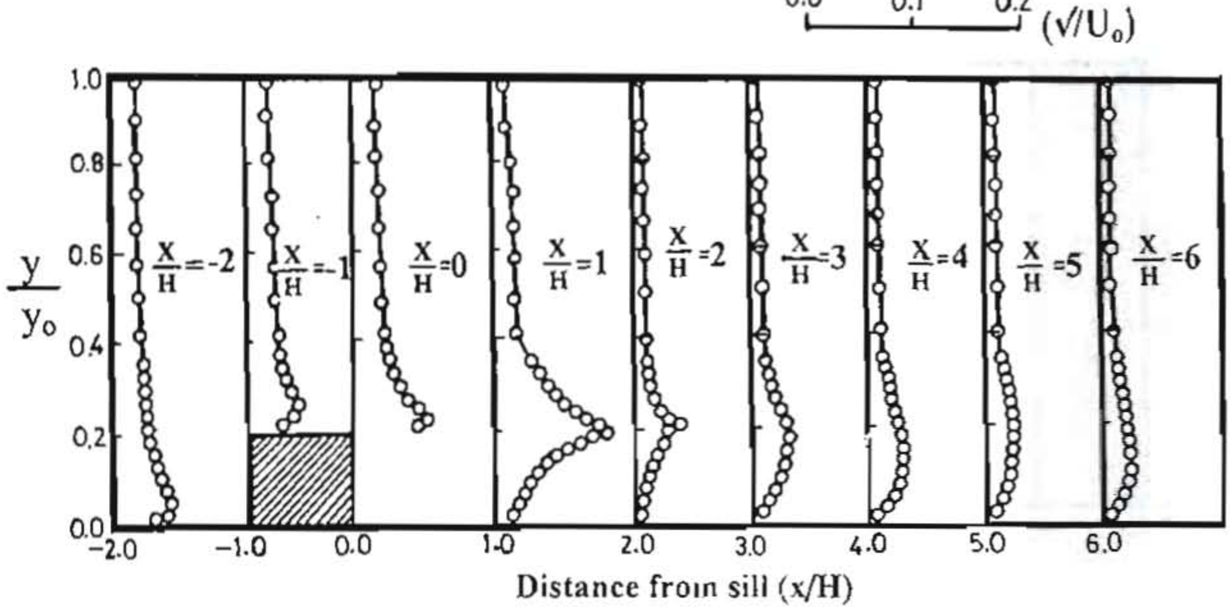

Fig. (8) Variation of vertical turbulence intensity (v'/U_o) with y/y_o upstream, above and downstream the sill.

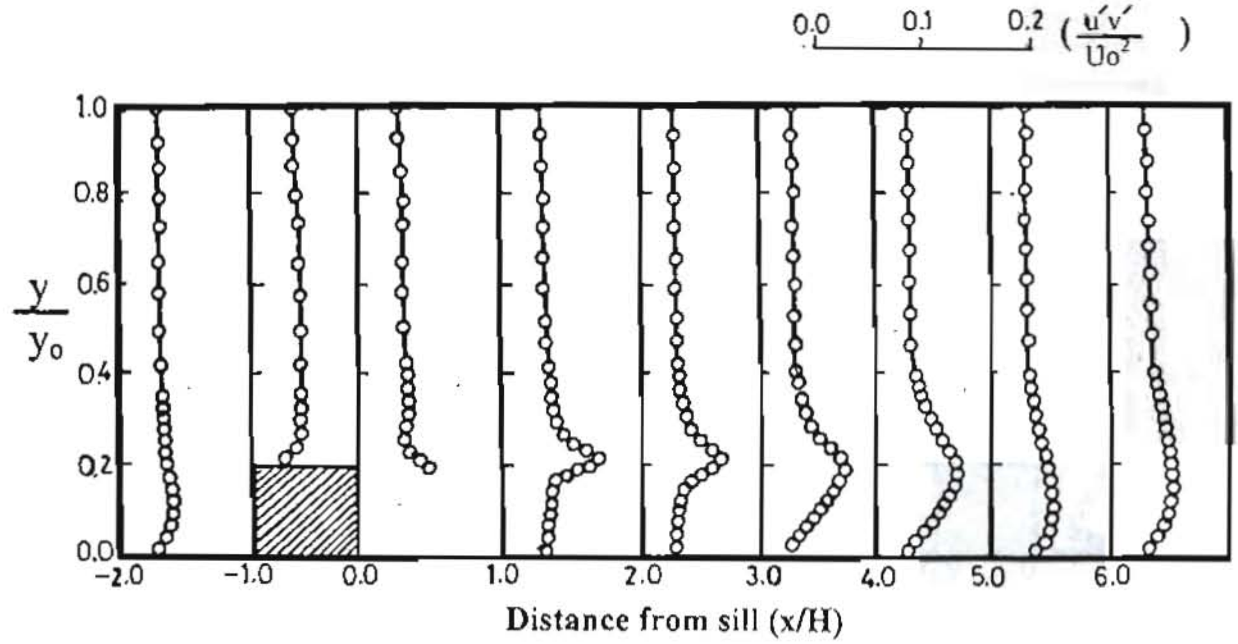

Fig. (9) Variation of turbulent shear stress $u'v'/U_o^2$ with y/y_o upstream, above and downstream the sill.