VELOCITY DISTRIBUTION FOR AN OPEN CHANNEL FLOW IN A SEMI-ELLIPTIC CHANNEL

A MASTER'S THESIS
IN
CIVIL ENGINEERING
Middle East Technical University

By
Celal Tibet ABAÇ
December 1987

Approval of the Graduate School of Natural and Applied Sciences .

Prof.Dr. Halim Dogrusoz

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Civil Engineering .

Prof.Dr. Turhan Erdogan

Chairman of the Civil Engineering Department

We certify that we read this thesis and that in our opinion it is fully adequate , in scope and quality as a thesis for the degree of Master of Science in Civil Engineering .

Asst.Prof.Dr. Nuray (Denli) Tokyay

Supervisor

Examining Committee

Assoc. Prof. Dr.	Semra SIBER
Assoc. Prof. Dr.	Mustafa GOGUS
Asst. Prof. Dr.	Ali GUNYAKTI
Asst. Prof. Dr.	Nuray TOKYAY
Civil Engineer	Bilge SABUNCU

bilge

ABSTRACT

Velocity Distribution for an Open Channel Flow in a Semi-Elliptic Channel

ABAÇ , Celal Tibet
M.S. in Civil Engineering
Supervisor : Asst. Prof. Dr. Nuray (Denli) Tokyay
September 1987 ,80 pages

The velocity distribution in an open channel flow is a very complex problem because of the existence of the free surface. Although detailed knowledge about the velocity distribution is needed in many problems , there is no well-established formula.

In this study ,the law of the wall which describes the velocity distribution for an open channel flow in a semi-elliptical channel , has been derived by using the equations of motion in elliptical-cylindrical coordinate system.

The values of the constants of the derived form of the law has been determined by using the available data for an open channel flow in a semi-elliptical channel and these values are compared with the corresponding values of the classical law of the wall.

Keywords : Open channel flow , velocity distribution , law of the wall.

ÖZET

Yarım-Elliptik Bir Kanalda Açık Kanal Akımı İçin Hız Dağılımı

ABAÇ , Celal Tibet

Yüksek Lisans Tezi , İnşaat Mühendisliği Bölümü
Tez Yöneticisi Y.Doç.Dr.Nuray (Denli) Tokyay
Aralık 1987 , 80 sayfa

Serbest yüzeyin varlığı nedeniyle , açık kanal akımlarında hız dağılımı çok karmaşık bir problemdir. Birçok problemde hız dağılımı hakkında detaylı bilgi gerekmesine rağmen , yeterli bir denklem bulunmamaktadır .

Bu çalışmada , yarım eliptik bir kanaldaki açık kanal akımı için hız dağılımını tanımlayan cidar yasası ,eliptik-silindirik koordinatlarda yazılmış hareket denklemleri kullanılarak türetilmiştir .

Türetilen cidar yasası'ndaki sabitlerin değeri yarım-eliptik bir kanaldaki açık kanal akımı için varolan veriler kullanılarak hesaplanmış ve bu değerler klasik cidar yasası'ndaki değerleri ile karşılaştırılmıştır.

Anahtar sözcükler : Açık kanal akımı , hız dağılımı , cidar yasası .

ACKNOWLEDGEMENTS

This study was suggested and has been carried out under the supervision of Ass.Prof.Dr. Nuray (Denli) Tokyay in Hydromechanics Laboratory of Civil Enginering Department at M.E.T.U. in Ankara , Turkey.

The author is indebted to Asst.Prof.Dr. Nuray (Denli) Tokyay for her helps which were more than a supevision. Without her helps this thesis would not have been possible.

TABLE OF CONTENTS

Page

CHAPTERS

LIST OF FIGURES

LIST OF TABLES

SYMBOLS

B	Constant in the law of the wall.
f	Body force per unit weight.
g	Gravitational acceleration.
h	Metric coefficient for x coordinate.
h_η	Metric coefficient for η coordinate.
h_ζ	Metric coefficient for ζ coordinate.
l	Mixing length.
P	Wetted perimeter.
r_o	Radius of a cylinder.
R	Hydraulic radius , defined as $R=A/P$.
S_o	Channel bottom slope.
S_{crit}	Critical slope.
T	Top width , the width of the free surface.
u	Velocity component in x direction.
$\bar{u}$	Mean flow velocity.
u'	Fluctuating velocity component.
u_τ	Shear velocity , defined as $\sqrt{\tau_o/\rho}$.
u^*	Dimensionless velocity , defined as $\bar{u}/u_\tau$.
v	Velocity component in y direction.
v'	Fluctuating velocity component.
w	Velocity component in z direction.
y	Distance from the channel boundary.
y^*	Dimensionless distance from the boundary , defined as yu_τ/ν .

γ	Specific weigth.
η	Coordinate in orthogonal curvilinear coordinate system.
μ	Dynamic viscosity.
k	von Karman’s universal constant,equal to 0.418.
ξ	Coordinate in orthogonal curvilinear coordinate system.
ρ	Density of water.
σ	Stress tensor.
τ	Total shear stress.
τ_0	Wall-shear stress.
ν	Kinematic viscosity.

CHAPTER I.

INTRODUCTION AND LITERATURE SURVEY

1.1 Velocity Distribution In Open Channels

The flow in an open channel , regardless of its geometric formation , is generally three-dimensional. The component in the longitudinal direction may be called as "the primary flow". The other two components in a cross-section combine to the form so called "the secondary flow".

The secondary flow velocity components are usually small compared to the primary flow velocity component , and hence in most of the open channel flow studies , the flow is usually considered as one-dimensional. The existence of a free surface and wide variation of the geometric shape in an open channel flow makes the analysis quite complicated. On the other hand , the flow in an open channel is almost invariably turbulent. As a result , there is no well-established velocity distribution formula , even for a one-dimensional uniform open channel flow . However , many problems , such as those involving mass or heat transfer , require a detailed knowledge of the velocity and boundary-shear distributions. In turbulent flows , whether closed conduit or open channel flow , the researchers assume that the velocity distribution normal to the wall follows the so called "law of the wall".

In this study, the law of the wall for an open channel flow in a semi-elliptical channel is investigated. In the subsequent sections, a brief description of the classical law of the wall and the literature survey will be discussed.

1.2 The Classical Law of the Wall

In a fully-developed turbulent flow over a smooth boundary, the velocity distribution, next to the boundary, depends upon only the wall-shear stress τ_o, the distance from the boundary y, the viscosity μ and the density ρ, that is

$$\bar{u} = f(\ \tau_o\ ,\ y\ ,\ \mu\ ,\ \rho\ ) \tag{1.1}$$

where $\bar{u}$ is the mean velocity in the direction of the flow. Dimensional analysis, applied to these variables gives the functional relation

$$\frac{\bar{u}}{u_\tau} = u^* = f(\ y^*\ ) \tag{1.2}$$

in which $u_\tau = \sqrt{\tau_o/\rho}$ is so called shear velocity, u^* is the dimensionless velocity and $y^* = u_\tau y / \nu$ is a dimensionless distance from the boundary.

Therefore, in the wall region, the nondimensional velocity distribution, $\bar{u} / u_\tau$, is a function of dimensionless distance y^*.

The other important assumption in this region is that the total shear stress is almost constant and equal to the wall-shear stress , that is

$$\tau = \mu \frac{\partial \bar{u}}{\partial y} - \rho \overline{u'v'} \approx \tau_0 \qquad (1.3)$$

where τ_0 is the total shear stress, $\mu\, \partial \bar{u} / \partial y$ is the viscous stress and $-\rho \overline{u'v'}$ is the Reynolds stress due to the fluctuating velocity components u' and v'.

In this region , although the shear stress is constant and equal to the wall-shear stress , there are three different regions depending on the relative magnitudes of the viscous and the Reynolds stresses. These regions are the viscous sublayer , the buffer zone and the fully-turbulent region .

Viscous Sublayer

In this region the shear stress is controlled by the dynamic viscosity of the fluid μ .Since the viscous sublayer is a very thin region next to the boundary , the fluctuating velocity components u' and v' are almost zero , and the flow is laminar.

Consequently , the shear stress is only due to the viscous part , and the velocity distribution is

$$u^* = y^* \qquad (1.4)$$

This region is valid up to the y^* is equal to 5.

Buffer Zone (Transition Zone)

Proceeding beyond the viscous sublayer , the flow begins to change from laminar flow to turbulent flow and the total stress is partly viscous and , partly turbulent. The orders of the magnitude of the viscous and the turbulent stresses are almost the same. This region is called as buffer zone , and there is no universal relation for the velocity distribution at this zone.

Buffer zone is valid in the range $5 < y^* < 30$ to 70 .

Fully-Turbulent Zone

At this region , the flow is fully turbulent and the Reynolds stress overdominates the viscous stress. Although, the shear stress still can be considered as constant and equal to the wall-shear stress , the shear stress is solely due to the momentum transfer occuring between fluid layers by fluctuations , i.e. due to the Reynolds stress ;

$$\tau = -\rho\,\overline{u'v'} \cong \tau_o \qquad (1.5)$$

On the other hand, Prandtl's mixing-length theory re relates the Reynolds stresses to the velocity distribution as

$$-\rho\,\overline{u'v} = \rho\, l^2 \left| \frac{\partial \bar{u}}{\partial y} \right| \cong \tau_o \qquad (1.6)$$

where l is so called mixing-length and is given by

$$l = k\ y \qquad (1.7)$$

In this expression k is assumed to be constant which is known as von Karman's constant and equal to 0.418 . If

Equation (1.6) is rearranged and integrated , the well-known logarithmic velocity distribution can be obtained as

$$\frac{\bar{u}}{u_\tau} = \frac{1}{k} \ln y^* + B \qquad (1.8)$$

1.3 Literature Survey

The classical law of the wall is accepted by most of the researchers such as Bakhmeteff,B.A. (1) , Chow, V.T. (2) , Daily,J.V.R. & Harleman,D.R.F. (3) , Cebeci,T. & Smith,A.M.O. (4) and Deissler,R.G. & Taylor,M.F. (5) .

Tracy,H.J. (6) assumed the velocity distribution of a channel flow as

$$\frac{\bar{u}}{u} = C_1 + C_2 \log \frac{y\, u_\tau}{\nu} \qquad (1.9)$$

in which C_1 and C_2 are constants , corresponding to the values of 3.5 and 6.5 respectively.

Van Den Berg,B. (7) derived the law of the wall for a three dimensional open channel flow , taking the effect of pressure gradient and inertial forces , into account. This three dimensional law of the wall also predicts the rotation of the velocity vector near to the wall. Van Den Berg,B. (7) gives the velocity distributions along the x and z directions as

$$u_x^* = \frac{1}{k} \left[\ln y^* + A + \frac{1}{2} \alpha_x y^* + \frac{1}{2} \beta_x \frac{(\ln y^*)^2\, y^*}{k} \right] \qquad (1.10)$$

and

$$u_z^* = \frac{1}{k}\left[\alpha_z(y^* + b) + \beta_z \frac{(\ln y^*)^2 y^*}{k}\right] \tag{1.11}$$

Here u_x^* is the dimensionless velocity in the wall-shear stress direction , u_z^* is the dimensionless velocity in the crosswise direction. The constants A and b are integration constants , and

$$\beta_x = \frac{\nu}{u_\tau^2}\frac{\partial u}{\partial x} \qquad \beta_z = \frac{\nu}{u_\tau^2}\frac{\partial u}{\partial z} \tag{1.12}$$

$$\alpha_x = \frac{\nu}{u_\tau^3}\frac{\partial P}{\partial x} \qquad \alpha_z = \frac{\nu}{u_\tau^3}\frac{\partial P}{\partial z} \tag{1.13}$$

Chiu,C-L. , Lin,H-C. & and Mizumura,K. (8) , in their study gave a different form of the law of the wall for Rio Grande Channel as

$$\frac{u}{u_\tau} = \frac{1}{k}\ln\frac{\xi}{\xi_0} \tag{1.14}$$

in which ξ is a curvilinear coordinate system representing an isovel along which u is constant and ξ_0 is a constant representing the channel boundary .

This form of the law of the wall may hold true for the velocity distribution of a natural channel such as Rio Grande Channel but it is not applicable to a geometrically defined cross-section . The ξ values which are accepted as isovels by Chiu,C-L. , Lin,H-C. & Mizumura,K. (8) , are increasing from channel boundary to the center of the channel.On the other hand for an elliptical channel defined by an elliptical-curvilinear coordinate system the ζ values decrease from channel boundary ζ_0 to the center of the channel. Consequently ,the Equation (1.14) gives negative values of velocity which is impossible .

1.4 Scope of the Present Study

In turbulent flows , whether it is external or internal , that is whether it is a flow around bodies or a flow in a conduit , the law of the wall is assumed to be valid next to the solid boundary.

For open channel flows , as explained in previous section there is no well-established form of the law of the wall. In this thesis , the form of the law of the wall , and hence the velocity distribution for an open channel flow in a semi-elliptic channel is investigated.

In the analysis ,an elliptical-cylindrical coordinate system is used. Equations of motion is written in this orthogonal curvilinear coordinates.By using these equations and Prandtl's mixing-length theory , a form of the law of the wall is established and applied to an existing data obtained for a semi-elliptical open channel.

CHAPTER II.

EQUATIONS OF MOTION

2.1 General Remarks

The velocity distribution in a uniform channel flow will become stable when the turbulent boundary layer is fully developed. In the turbulent boundary layer over smooth surfaces ,the law of the wall describes the velocity distributions near the walls. As discussed in previous chapter , an assumption in the derivation of the classical law of the wall is that the shear stress is constant and equal to the wall-shear stress in the thin layer near the wall. The constancy of the shear stress can be obtained from the equations of motion and is valid if the boundaries are straight as in rectangular channels. On the other hand, for flows in or over circular boundaries , due to the curvature effects of the boundary , the equations of motion gives that , not the stress itself but the stress moment $r\tau$, is constant and equal to $r_0 \tau_0$, where r_0 is radius of the cylinder and τ_0 is the wall-shear stress. Consequently , the law of the wall differs than the classical law of the wall as discussed by many researchers , such as Rao , G.N.V. , (9) , Patel , V.C. (10) , Denli , N. (11).

In this study , a uniform open channel flow in a semi-elliptical channel is investigated . Hence , to determine the effect of boundary curvature on the shear stress distribution and consequently on the law of the wall ,it will be the best to use elliptical-cylindrical coordinates in the analysis of the flow.

In the subsequent sections,the elliptical-cylindrical coordinates will be described first , then to determine how the shear stress varies , the equations of motion will be given in these orthogonal curvilinear coordinates.

2.2 The Elliptical - Cylindrical Coordinates

The elliptical-cylindrical coordinates , shown in Figure (2.1) may be defined by the equations

$$x = x \tag{2.1 a}$$

$$y = \alpha \cosh \xi \cos \eta \tag{2.1 b}$$

$$z = \alpha \sinh \xi \sin \eta \tag{2.1 c}$$

$$\alpha = \sqrt{a^2 - b^2} \tag{2.1 d}$$

where $\xi \geqslant 0$ and $0 \leqslant \eta \leqslant 2\pi$, a and b are major and minor axes of the confocal ellipses .

From the equations (2.1 b) and (2.1 c) , it can be shown that ,

$$\frac{y^2}{(\alpha \cosh \xi)^2} + \frac{z^2}{(\alpha \sinh \xi)^2} = 1 \tag{2.2}$$

which is the equation of an ellipse with the semi-axes

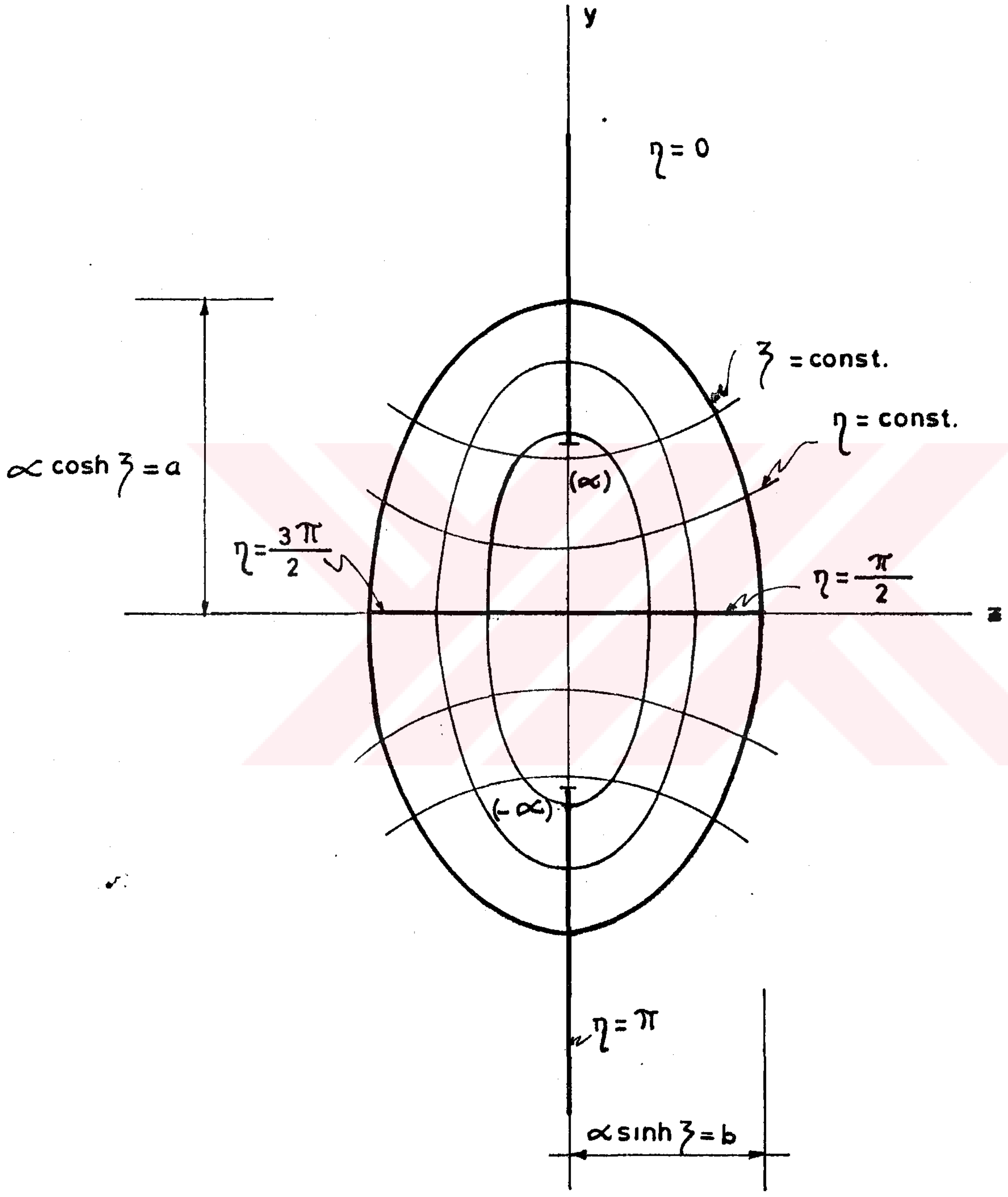


FIG. (2.1) SCHEMATIC REPRESANTATION OF ELLIPTICAL - CYLINDRICAL COORDINATES

$\alpha\cosh\xi$ in the y-direction and $\alpha\sinh\xi$ in the z-direction . Therefore in the yz plane , a curve ξ = constant is an ellipse with the semi-axes $\alpha\cosh\xi$ and $\alpha\sinh\xi$. In particular ,the locus $\xi = 0$ degenerates into the segment $(-\alpha, \alpha)$ between the foci.

From the Equations (2.1 b) and (2.1 c) , it can also be shown that

$$\frac{y^2}{(\alpha\cos\eta)^2} - \frac{z^2}{(\alpha\sin\eta)^2} = 1 \qquad (2.3)$$

which is the equation of a hyperbola with semi-axes $\alpha\cos\eta$ and $\alpha\sin\eta$. Therefore , a curve η = constant is half of one branch of an hyperbola with semi-axes $\alpha\cos\eta$ and $\alpha\sin\eta$ .In particular , the loci $\eta = 0$ and $\eta = \pi$ are , respectively , the positive and negative exteriors of the segment $(-\alpha, \alpha)$ which is defined by the curve $\xi = 0$. Also , the loci $\eta = \pi / 2$ and $\eta = 3\pi / 2$ are , respectively ,the positive and negative portions of the z-axis.

On the other hand , the x-axis is normal to the yz plane. The metric coefficients for the elliptical-cylindrical coordinates defined above are (Hildebrand (12))

$$h_\xi = h_\eta = \alpha\sqrt{\cosh^2\xi - \cos^2\eta} = h \qquad (2.4)$$

$$h_x = 1 \qquad (2.5)$$

Since in this study a uniform flow in a semi-elliptical channel is considered , $\xi = \xi_0$ defines the channel boundary at a cross-section and x-axis is the direction of the primary flow. On the other hand , as shown in Figure (2.1) , the value of $\eta = 0$ is the upper half of the ellipse and $\eta = \pi$ is on the lower half. Since it would not make any difference , consistent with the geometry ,the centerline of the channel is taken as $\eta = 0$ in this study.

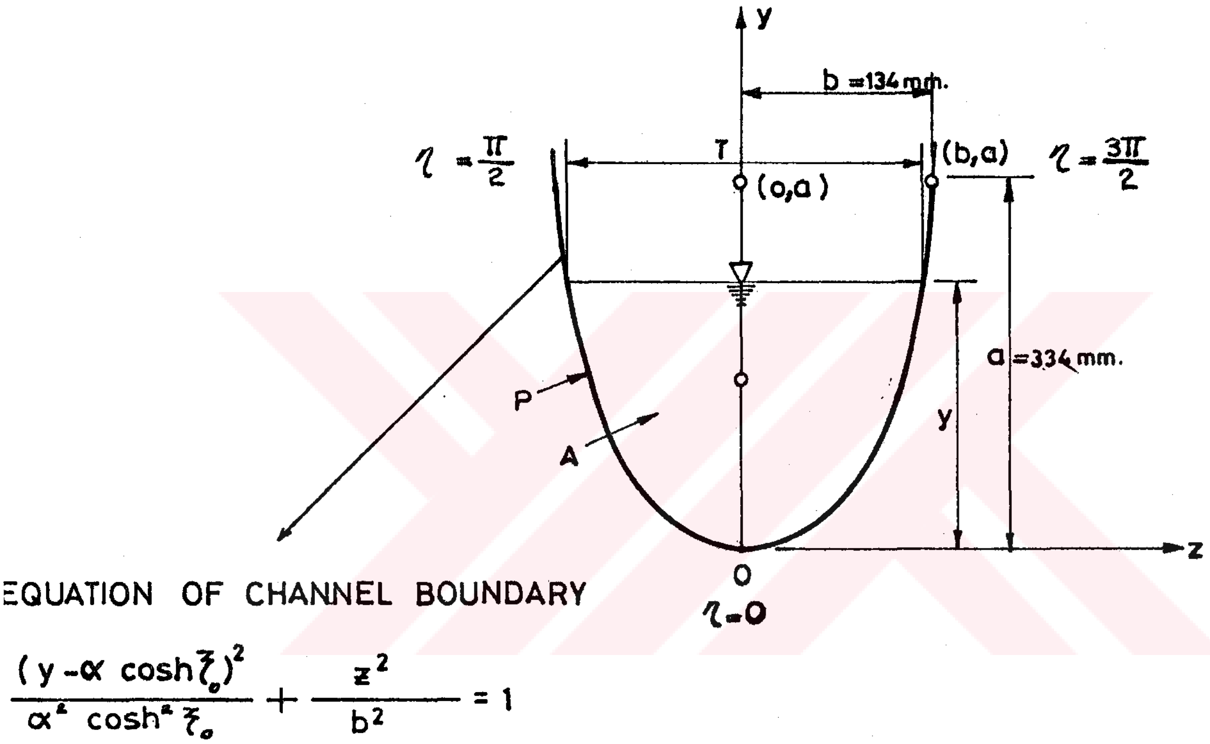
In particular , for the semi-elliptical channel in which the velocity and the wall-shear stress measurements were taken , the value of ξ_0 is 0.425 and the value of α is 0.30594 m.. A schematic representation of the channel cross-section and the equation of the channel geometry and the range of η are shown in Figure (2.2) .

2.3 Equations Of Motion In Orthogonal Curvilinear Coordinates

Any fluid flow should satisfy the equation of continuity and the linear-momentum equations . In the following sections , the equations of the continuity and momentum will be given for a general orthogonal curvilinear coordinate system and then they will be reduced to the elliptical-cylindrical coordinates.

Orthogonal Curvilinear Coordinates

Let (x_1 , x_2 , x_3) be an orthogonal curvilinear coordinates with the corresponding metric coefficients



$$\frac{(y-\alpha\cosh\xi_o)^2}{\alpha^2\cosh^2\xi_o} + \frac{z^2}{b^2} = 1$$

FIG. 2.2 GEOMETRICAL ELEMENTS OF A SEMI-ELLIPTICAL SECTION.

(h_1 , h_2 , h_3) , and $\underset{\sim}{u} = (u_1 , u_2 , u_3)$ be the velocity vector with the components (u_1 , u_2 , u_3) along (x_1 , x_2 , x_3) directions , respectively.

The Equation of Continuity

For an incompressible fluid the continuity equation is ,

$$\text{div}\ \underset{\sim}{u} = \underset{\sim}{\nabla} . \underset{\sim}{u} = 0 \tag{2.6}$$

in which the divergence operator in orthogonal curvilinear coordinate system may be written as (Rouse , H.(13))

$$\frac{1}{h_1\ h_2\ h_3}\left[\frac{\partial}{\partial x_1}(h_2 h_3 u_1) + \frac{\partial}{\partial x_2}(h_1 h_3 u_2) + \frac{\partial}{\partial x_3}(h_1 h_2 u_3)\right] = 0 \tag{2.7}$$

2.3.3 The Linear - Momentum Equation

The linear-momentum equation in terms of nabla operator $\underset{\sim}{\nabla}$ may be written as

$$\frac{\partial \underset{\sim}{u}}{\partial t} + (\underset{\sim}{u} . \underset{\sim}{\nabla})\ \underset{\sim}{u} = \underset{\sim}{f} + \frac{1}{\rho}\ \underset{\sim}{\nabla} . \underset{\sim}{\sigma} \tag{2.8}$$

in which $\underset{\sim}{f} = (f_1 , f_2 , f_3)$ is the body force per unit mass and $\underset{\sim}{\sigma}$ is the stress tensor and ρ is the density.

For a steady uniform flow along the x_1- direction the acceleration terms given by the left hand side of the equation will be zero , and along the x_1 - direction the stress tensor $\underset{\sim}{\sigma}$ have the components (σ_{11} , τ_{21} , τ_{31}). If the gravity , g , is the only body force , and z is the vertical direction , then along the x_1- direction f_1 is given by

$$f_1 = - g \frac{1}{h_1} \frac{\partial z}{\partial x_1} \tag{2.9}$$

With the substitution of Equation (2.9) into Equation (2.8) , the linear-momentum equation for a steady uniform flow along the x_1 - direction will be reduced to

$$0 = -g \frac{1}{h_1} \frac{\partial z}{\partial x_1} + \frac{1}{\rho} \frac{1}{h_1 h_2 h_3} \left[\frac{\partial}{\partial x_1} (h_2 h_3 \sigma_{11}) + \frac{\partial}{\partial x_2} (h_1 h_3 \tau_{21}) + \frac{\partial}{\partial x_3} (h_1 h_2 \tau_{31}) \right] \tag{2.10}$$

2.4 Equations of Motion In Elliptical - Cylindrical Coordinates

The orthogonal curvilinear coordinate system used in this study is the elliptical-cylindrical coordinate system (x, ξ , η) with the metric coefficients $(1, h_\xi, h_\eta)$, respectively , in which $h_\xi = h_\eta = h$ as defined in Section (2.2).

Equation of Continuity

Let (u , v , w) be the velocity components along (x , ξ , η) directions respectively. Then the equation of continuity given by equation (2.7) will reduce to

$$\frac{\partial}{\partial x}(h^2 u) + \frac{\partial}{\partial \xi}(h\ v) + \frac{\partial}{\partial \eta}(h\ w) = 0 \qquad (2.11)$$

For a steady uniform flow in a semi-elliptical channel , with the chosen coordinate system , u will be the only velocity component for a unidirectional flow . Consequently , the velocity u will only be a function of ξ and η , i.e. $u = f(\xi , \eta)$. On the other hand , if ξ = constant curves may be considered as isovels , then the velocity u may become only a function of ξ , that is , that is , $u = f(\xi)$

The Linear - Momentum Equation

In elliptical-cylindrical coordinates , Equation (2.10) will become

$$0 = -g\frac{\partial z}{\partial x} + \frac{1}{\rho}\frac{1}{h^2}\left[\frac{\partial}{\partial x}(h^2\sigma_{xx}) + \frac{\partial}{\partial \xi}(h\,\tau_{\xi x}) + \frac{\partial}{\partial \eta}(h\,\tau_{\eta x})\right] \qquad (2.12)$$

Multiplying with and rearranging will yield

$$0 = -\gamma\frac{\partial z}{\partial x} + \frac{\partial \sigma_{xx}}{\partial x} + \frac{1}{h^2}\frac{\partial}{\partial \xi}(h\,\tau_{\xi x}) + \frac{1}{h^2}\frac{\partial}{\partial \eta}(h\,\tau_{\eta x}) \qquad (2.13)$$

For a steady uniform flow in a semi-elliptical channel , the variation of σ_{xx} along the flow direction will be zero , and as discussed above u is a function of ξ only. Consequently , the only shear stress must be $\tau_{\xi x}$ and $\tau_{\eta x}$ must be zero. On the other hand , $-(\partial z / \partial x)$ is nothing but the channel bottom slope S_o. Since $\tau_{\xi x}$ is the only shear stress which is acting on ξ = constant surfaces along the x - direction , let us omit the indices and simply call it as τ . Therefore , Equation (2.13) , with $\tau_{\xi x} = \tau$, will reduce to

$$0 = - \gamma S_o + \frac{1}{h^2} \frac{\partial}{\partial \xi} (h \tau) \tag{2.14}$$

Equation (2.14) can be integrated to give the stress distribution over the channel cross-section. As discussed in section (2.2) , $\xi = \xi_o$ is the channel boundary. Also the shear stress acting on ξ_o is nothing but the wall-shear stress τ_o . If h_o is the metric coefficient for $\xi = \xi_o$, then Equation (2.14) may be integrated as follows

$$\int_{h_o \tau_o}^{h \tau} d\,(h \tau) = - \gamma S_o \int_{\xi_o}^{\xi} h^2 \, d\xi \tag{2.15}$$

Substituting Equation (2.4) which is the expression for h , Equation (2.15) will be

$$h\tau - h_0\tau_0 = -\gamma S_0 \int_{\xi_0}^{\xi} \alpha^2(\cosh^2\xi - \cos^2\eta)\,d\xi \qquad (2.16)$$

Integration of the above equation then yields

$$h\tau - h_0\tau_0 = -\gamma S_0\alpha^2 \left[\frac{1}{2}\xi + \frac{1}{4}\sinh 2\xi - \xi\cos^2\eta \right]_{\xi_0}^{\xi} \qquad (2.17)$$

Let us define that the function $F(\xi,\eta)$ as the term in the paranthesis in Equation (2.17) , i.e.

$$F(\xi,\eta) = \frac{1}{2}\xi + \frac{1}{4}\sinh 2\xi - \xi\cos^2\eta \qquad (2.18)$$

Substituting Equation (2.18) and rearranging , Equation (2.17) may be written as

$$h\tau = h_0\tau_0 \left[1 - \frac{\gamma S_0\alpha^2[F(\xi,\eta) - F(\xi_0,\eta)]}{h_0\tau_0} \right] \qquad (2.19)$$

As can be seen from Equation (2.18) , for small values of ξ , the order of magnitude of the function $F(\xi,\eta)$ is given by the order of ξ . For the channel under consideration , the values of α , ξ_0 and h_0 are 0.306 , 0.425 and 0.334 ,respectively . The specific weight , γ , of water is 10000 N/m . For the data of Taymaz ,Y.K. (14) , the maximum value of τ_0 is 1000 N/m for a slope of S_0 = 0.020.

Therefore , for these values and for ξ = 0.325 , the order of magnitude of the last term in Equation (2.19) may be estimated as

$$O\left[\frac{\gamma S_o \alpha^2 (\xi - \xi_o)}{h_o \tau_o}\right]$$

$$\sim \frac{(10000)(0.02)(0.0306)\ (0.325-0.425)}{(0.334)(1000)}$$

$$\sim \quad 0.006$$

Therefore the last term contributes very little , then Equation (2.19) may be approximated by

$$h\,\tau = h_o\,\tau_o \tag{2.20}$$

$h\,\tau$ may be considered a kind of stress moment , and Equation (2.20) shows that the stress moment is constant near the wall which is similar to the case in circular boundaries. As discussed in Section (2.1) , for circular boundaries , the stress moment $r\,\tau$ is constant near the wall and equal to $r_o\,\tau_o$, where r_o is the radius of the boundary .

2.5 Relation Between The Velocity and The Shear Stress Distribution

For a steady uniform turbulent open channel flow , the total shear stress at a point may be written as

$$\tau = \mu \frac{\partial \bar{u}}{\partial n} - \rho \overline{u'v'} \tag{2.21}$$

which is the sum of the viscous and Reynolds stresses , and n is a direction measured normal to the boundary. μ is the dynamic viscosity of the water. u' and v' are the fluctuating velocity components along the x and n directions, respectively. If the Reynolds stress is related to the mean velocity distribution via the mixing-length theory , Equation (2.21) becomes

$$\tau = \mu \frac{\partial \bar{u}}{\partial n} + \rho l^2 \left(\frac{\partial \bar{u}}{\partial n} \right)^2 \tag{2.22}$$

Introducing the usual nondimensional quantities , defined in the following way

$$u^* = \frac{\bar{u}}{u_\tau} , \quad n^* = \frac{u_\tau n}{\nu} , \quad l^* = \frac{u_\tau l}{\nu} , \quad \tau^* = \frac{\tau}{\tau_0}$$

$$\text{and} \quad u_\tau = \sqrt{\frac{\tau_0}{\rho}} \tag{2.23}$$

where ν is the kinematic viscosity of the fluid and τ_0 is the shear stress at the wall , $n = 0$, Equation (2.22) may be written as

$$\left[l^* \frac{\partial \bar{u}^*}{\partial n^*} \right]^2 + \left[\frac{\partial \bar{u}^*}{\partial n^*} \right] - \tau^* = 0 \tag{2.24}$$

Solution of this quadratic yields that ; (Patel (10)) ;

$$\frac{\partial u^*}{\partial n^*} = \frac{2\,\tau^*}{1 + [\,1 + 4\,l^{*^2}\,\tau^*\,]^{1/2}} \qquad (2.25)$$

Since $u^* = 0$ at $n = 0$, the integration of Equation (2.25) yields

$$u^* = \int_0^{n^*} \frac{2\,\tau^*}{1 + [\,1 + 4\,l^{*^2}\,\tau^*\,]^{1/2}}\, d\,n^* \qquad (2.26)$$

This is a relation between the velocity distribution and the stress distribution. In order to proceed further , it is necessary to prescribe the function l^* and also the variation of τ^* with n^* .

2.6 Velocity Distribution For A Steady Uniform Flow In A Semi - Elliptical Channel

In order to obtain the velocity distribution from Equation (2.26) , it is necessary to know the shear stress distribution through the wall region. The shear stress distribution is , in general , dependent upon the geometry of the flow. For a steady uniform flow in a semi-elliptical channel , the shear stress distribution is obtained from equation of motion and is given by Equation (2.20). In nondimensoinal form Equation (2.20) may be written as

$$\tau^* = \frac{\tau}{\tau_o} = \frac{h_o}{h} \qquad (2.27)$$

Generally , the flow in the wall region is subdivided into three regions,namely a) the viscous sublayer , b) the the buffer zone , c) the fully turbulent zone.

In the viscous sublayer , the Reynolds stresses are generally assumed to be negligible compared to viscous stresses ; hence the mixing length is $l^* = 0$. With $l^* = 0$ and $\tau^* = h_o/h$, Equation (2.26) gives the sublayer relation as

$$u^* = \int_0^{n^*} \frac{h_o}{h} \, d\, n^* \tag{2.28}$$

In this expression n^* is the distance normal to the channel boundary . In terms of elliptical-cylindrical coordinates ,

$$d\, n = - h_\xi \, d\xi = - h \, d\xi$$

and (2.29)

$$d\, n^* = \frac{u_\tau}{\nu} \, d\, n = - \frac{u_\tau}{\nu} \, h \, d\xi$$

Substituting Equation (2.29) into Equation (2.28) ,and with when $n = 0$, $\xi = \xi_o$, Equation (2.28) gives that

$$u^* = \int_{\xi_o}^{\xi} - \frac{h_o}{h} \, \frac{u_\tau}{\nu} \, h \, d\xi = \int_{\xi_o}^{\xi} - \frac{u_\tau \, h_o}{\nu} \, d\xi \tag{2.30}$$

and hence the viscous sublayer relation becomes

$$u^* = \frac{u_\tau \, h_o}{\nu} \, (\xi_o - \xi) \tag{2.31}$$

For flat surfaces , the viscous sublayer relation is

$$u^* = y^* = \frac{u_\tau \, y}{\nu} \quad , \quad y^* < 5 \tag{2.32}$$

Since $h_o \, (\zeta_o - \zeta)$ represents the distance normal to the boundary , Equation (2.31) represents a generalization of the linear relation for elliptical boundaries. For the fully turbulent region , the viscous stresses are generally neglected in comparison with the Reynolds stresses , and the mixing-length is taken as $l^* = k \; y^*$. Hence , this suggests , by direct analogy , that in the fully turbulent region , the mixing length should be replaced by

$$l^* = k \, \frac{u_\tau \, h_o}{\nu} \, (\zeta_o - \zeta) \tag{2.33}$$

Once the distribution of the shear stress and the mixing - length are established , the velocity distribution in the fully turbulent zone can be obtained from Equation (2.26). Also , in this region , from order-of-magnitude considerations , Equation (2.26) can be simplified as follows ; in the fully turbulent region $4 \, l^{*^2} \, \tau^*$ is much greater than one. Hence , Equation (2.26) reduces to

$$u^* = \int \frac{\sqrt{\tau^*} \; d \, n^*}{l^*} + C \tag{2.34}$$

where C is a constant of integration that should be introduced ; because the limits of integration and the buffer zone are not considered.

Substitution of Equations (2.27) , (2.29) and (2.33) into Equation (2.34) then yields that

$$u^{*} = \int \frac{-\sqrt{\dfrac{h_o}{h}}\;\dfrac{u_\tau}{\nu}\;h\;d\xi}{k\;\dfrac{u_\tau}{\nu}\;h_o\,(\xi_o - \xi)} + C \qquad (2.35)$$

Equation (2.35) can be simplified and rearranged as

$$u^{*} = -\frac{1}{k}\int \frac{\sqrt{\dfrac{h}{h_o}}\;d\xi}{(\xi_o - \xi)} + C \qquad (2.36)$$

On the other hand , from equation (2.4) , the ratio of h / h is given by

$$\frac{h}{h_o} = \sqrt{\frac{\cosh^2\xi - \cos^2\eta}{\cosh^2\xi_o - \cos^2\eta}} \qquad (2.37)$$

Substitution of Equation (2.37) into Equation (2.36), then gives the velocity distribution in the fully turbulent region as

$$u^{*} = -\frac{1}{k}\int \frac{(\cosh^2\xi - \cos^2\eta)^{1/4}\;d\xi}{(\cosh^2\xi_o - \cos^2\eta)^{1/4}\;(\xi_o - \xi)} + C \qquad (2.38)$$

The integral in Equation (2.38) is an elliptical integral , and there is no analytical solution of it. On the other hand , if ξ curves may be considered as approximating the isovels , then the velocity u will be only function of ξ , and hence the dependence of u on η may be neglected . Therefore , the integral can be approximated for specific value of $\eta = \pi$. For $\eta = \pi$, Equation (2.38) reduces to

$$u^* = -\frac{1}{k} \int \frac{\sqrt{\sinh \xi} \quad d\xi}{\sqrt{\sinh \xi_0} \quad (\xi_0 - \xi)} + C \qquad (2.39)$$

Even in this form , there is no analytical solution to Equation (2.39). On the other hand , the series expansion of sinh ξ term is

$$\sinh \xi = \sum_{m=0}^{\infty} \frac{\xi^{(2m+1)}}{(2m+1)!}$$

$$= \xi + \frac{\xi^3}{3\,!} + \frac{\xi^5}{5\,!} + \text{higher order terms} \qquad (2.40)$$

Therefore , for small values of ξ , with $\sinh \xi \cong \xi$, equation (2.39) may be written as

$$u^* = -\frac{1}{k\sqrt{\sinh \xi_0}} \int \frac{\sqrt{\xi} \quad d\xi}{(\xi_0 - \xi)} + C \qquad (2.41)$$

Equation (2.41) can be integrated analytically (Gradstein and Ryzik (15)) as

$$u^{*} = - \frac{1}{k \sqrt{\sinh \zeta_0}} \left[-\sqrt{\zeta_0} \ln \left| \frac{\zeta_0 + \zeta - 2\sqrt{\zeta_0 \zeta}}{\zeta_0 - \zeta} \right| - 2\sqrt{\zeta} \right] + C \qquad (2.42)$$

Equation (2.42) can be rearranged as

$$u^{*} = \frac{\zeta_0}{k \sqrt{\sinh \zeta_0}} \left[\ln \frac{1 - \sqrt{\frac{\zeta}{\zeta_0}}}{1 + \sqrt{\frac{\zeta}{\zeta_0}}} + 2\sqrt{\frac{\zeta}{\zeta_0}} \right] + B \qquad (2.43)$$

where B is the constant of integration together with C .

In Equation (2.40) , $\sinh \zeta$ is approximated as $\sinh \zeta \cong \zeta$. Consistent with this approximation $\sqrt{\sinh \zeta_0}$ can be taken as ζ_0 , and hence Equation (2.43) will reduce to

$$u^{*} = \frac{1}{k} \ln \frac{1 - \sqrt{\frac{\zeta}{\zeta_0}}}{1 + \sqrt{\frac{\zeta}{\zeta_0}}} + \frac{2}{k} \sqrt{\frac{\zeta}{\zeta_0}} + B \qquad (2.44)$$

Therefore , the velocity distribution in the fully turbulent region may be given by Equation (2.44). The data of Taymaz,Y.K. (14) are compared with Equation (2.44) as explained in the following chapter .

CHAPTER III.

RESULTS AND DISCUSSION

In this thesis the velocity distribution in a semi-elliptical open channel flow has been studied. By using the linear - momentum equations in elliptical coordinates , and the mixing-length theory , a form of the law of the wall is obtained . This form is given by Equation (2.44)

On the other hand , in the classical law of the wall, the velocity distribution is given by Equation (1.8) . In these equations , Equation (1.8) and Equation (2.44) the k is known as von Karman's constant and it is universal . In literature the value of k is taken as 0.4 , but in 1967 , Patel,V.C.(10) has shown that the value of k is 0.418 . On the other hand constant B is not universal but it may take different values for different flows.

To check the value of k and to determine the constant B , Equation (2.44) has been put in the following form :

$$u^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}} = \frac{1}{k}\ln\left[\frac{1-\sqrt{\frac{\xi}{\xi_0}}}{1+\sqrt{\frac{\xi}{\xi_0}}}\right] + B \qquad (3.1)$$

and the data of Taymaz,Y.K. (14) have been used . Taymaz, Y.K. (14) measured the velocities and the wall – shear stresses for flows having different depths , discharges and slopes in a semi-elliptical open channel .

In this study the following data of Taymaz,Y.K. (14) have been used :

1. The data for horizontal slope which are labelled as H-Series . In this series the ones H-1 , H-2 , H-3 , H-6 which correspond to the depths 10.9 cm.,14.7 cm.,20.25 cm., and discharges 7.807 lt/sec.,14.766 lt/sec.,30.209 lt/sec., 45.096 lt/sec. , respectively , have been taken .

2. The data for mild slopes which are labelled as M-Series. In M1 series the ones M1-3 , M1-4 , M1-5 , M1-6 , M1-7 which correspond to the depths 10.3 cm. , 10.07 cm. , 13.82 cm.,19.5 cm.,25.25 cm., and discharges 9.808 lt/sec., 9.557 lt/sec.,19.295 lt/sec.,31.575 lt/sec.,52.906 lt/sec., respectively , have been taken . The slope of M1 series is 0.00295 .

In M2 series the ones M2-3 , M2-5 , M2-6 which correspond to the depths 10.0 cm., 15.44 cm., 20.44 cm., and discharges 11.167 lt/sec., 25.753 lt/sec., 41.193 lt/sec., respectively , have been taken . The slope of M2 series is 0.00450 .

3. The data for steep slopes which are labelled as S-Series.In S1 series the ones S1-2 , S1-3 , S1-4 , S1-5 which correspond to the depths 10.3 cm. , 15.36 cm. , 16.55 cm. , 20.22 cm. , and discharges 15.808 lt/sec. , 36.230 lt/sec., 36.282 lt/sec.,53.819 lt/sec., respectively have been taken . The slope of S1 series is 0.00923 .

In S2 series the ones S2-2 , S2-3 , S2-4 which correspond to the depths 11.02 cm.,14.98 cm.,19.45 cm., and discharges 20.989 lt/sec.,38.493 lt/sec.,61.353 lt/sec., respectively, have been taken . The slope of S2 series is 0.0173 .

For each set of data of Taymaz , Y.K. (14) , the ξ = constant and η = constant curves and their values corresponding to the measurement points have been determined and shown in Figure (3.0) . For each η = constant curve , the value of the wall-shear stress have been taken directly from data of Taymaz,Y.K. (14). Then along each η = constant curve , for each ξ value , the corresponding velocity have been determined either from the direct measurement or by interpolation . These computations are given in Tables (3.1) - (3.19) .

Also for each set of data , the values of $[u^{*}-(2/k)\sqrt{\xi/\xi_0}\,]$ versus $[\,1 - (\sqrt{\xi/\xi_0})\,] \,/\, [\,1 + (\sqrt{\xi/\xi_0})\,]$ have been plotted on semi-logarithmic papers , as shown in Figures (3.1) - (3.19) .

In each of these figures , the η values are changing from 11.31 to 59.78 . At Section (2.5) ,in the derivation of the law of the wall , it has been assumed that , if ξ curves may be considered as isovels , the primary flow velocity u , may be considered as a function of ξ only , and the dependence on η may be neglected . As can be seen from the figures , this assumtion is verified .

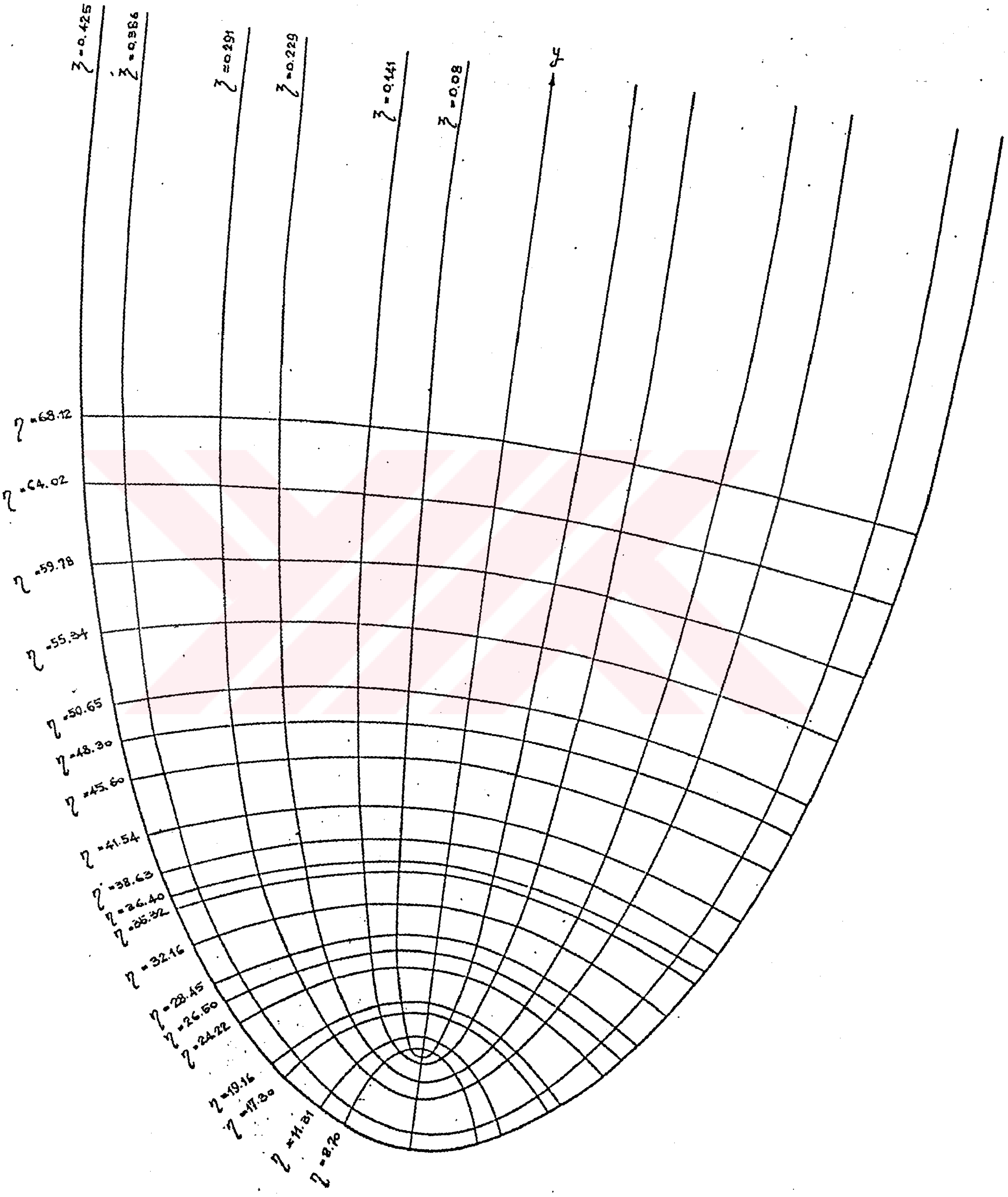


FIG. 3.0 SCHEMATIC REPRESENTATION OF THE CHANNEL CROSS-SECTION

H - 1 SERIES d = 10.90 cm. slope = 0.00000 Q = 7.807 lt/sec.

SECTION	η	ξ	h_{ξ} (m.)	h_{η} (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_{τ} (m./s.)	$\dfrac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \dfrac{2}{k}\sqrt{\dfrac{\xi}{\xi_0}}$
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.42960	0.02358	0.02536	18.21883	13.67078
D		0.29200	0.22200	0.24300	0.82889	0.53350	0.02358	0.09356	22.62511	18.65912
C		0.19700	0.21176	0.24300	0.68083	0.56070	0.02358	0.18989	23.77863	20.52107
B		0.09800	0.20509	0.24300	0.48020	0.58945	0.02358	0.35117	24.99788	22.70029
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.34988	0.02358	0.00959	14.83800	10.14424
D		0.31000	0.21400	0.23330	0.85406	0.52503	0.02358	0.07872	22.26590	18.17951
C		0.20900	0.20200	0.23330	0.70126	0.56745	0.02358	0.17560	24.06489	20.70958
B		0.10500	0.19400	0.23330	0.49705	0.58804	0.02358	0.33596	24.93808	22.55985
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.50890	0.02358	0.06697	21.58185	17.39776
C		0.21800	0.19400	0.22600	0.71620	0.56220	0.02358	0.16537	23.84224	20.41545
B		0.11000	0.18500	0.22600	0.50875	0.58440	0.02358	0.32560	24.78372	22.34952
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.49890	0.02358	0.06166	21.15776	16.92885
C		0.22400	0.19070	0.22260	0.72599	0.55762	0.02358	0.15876	23.64801	20.17438
B		0.11300	0.18110	0.22260	0.51564	0.58222	0.02358	0.31958	24.69126	22.22410
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.46560	0.02358	0.04078	19.74555	15.33581
C		0.24200	0.17900	0.21100	0.75459	0.53940	0.02358	0.13986	22.87532	19.26482
B		0.12200	0.16700	0.21100	0.53578	0.57490	0.02358	0.30227	24.38083	21.81730
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.36330	0.02358	0.01453	15.40712	10.75950
C		0.27100	0.16820	0.19800	0.79853	0.51520	0.02358	0.11202	21.84902	18.02832
B		0.13700	0.15170	0.19800	0.56776	0.56410	0.02358	0.27570	23.92282	21.20625
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.50220	0.02358	0.09526	21.29771	17.34533
B		0.14100	0.14320	0.19100	0.57599	0.55920	0.02358	0.26904	23.71501	20.95908
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.50480	0.02358	0.07238	21.40797	17.26919
B		0.16000	0.13480	0.18360	0.61357	0.56980	0.02358	0.23949	24.16455	21.22880
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.36820	0.02358	0.01957	15.61493	11.01389
B		0.20400	0.11850	0.16700	0.69282	0.52950	0.02358	0.18146	22.45547	19.14054
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.51960	0.02358	0.16537	22.03562	18.60883
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.48150	0.02358	0.07792	20.41985	16.32687

TABLE 3.1 Analysis of Data for H - 1 Series.

H - 2 SERIES d = 14.70 cm. slope = 0.00000 Q = 14.766 lt/sec.

SECTION	η	ζ	h_ζ (m.)	h_η (m.)	$(\zeta/\zeta_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\zeta/\zeta_0)^{0.5}}{1+(\zeta/\zeta_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\zeta}{\zeta_0}}$
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.48880	0.02881	0.00898	16.96633	12.26684
E		0.33100	0.25810	0.27190	0.88251	0.63020	0.02881	0.06241	21.87435	17.65181
D		0.25100	0.24900	0.27190	0.76850	0.68370	0.02881	0.13090	23.73134	20.05432
B		0.08400	0.23797	0.27190	0.44458	0.72730	0.02881	0.38449	25.24471	23.11755
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.61430	0.02881	0.05281	21.32246	17.01780
D		0.25900	0.24250	0.26500	0.78065	0.68370	0.02881	0.12319	23.73134	19.99618
C		0.17400	0.23460	0.26500	0.63985	0.71990	0.02881	0.21962	24.98785	21.92635
B		0.08700	0.22690	0.26500	0.45244	0.73020	0.02881	0.37699	25.34537	23.18056
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.59650	0.02881	0.03599	20.70462	16.25233
D		0.27100	0.23410	0.25640	0.79853	0.67990	0.02881	0.11202	23.59944	19.77874
C		0.18200	0.22560	0.25640	0.65440	0.71990	0.02881	0.20890	24.98785	21.85677
B		0.09100	0.22040	0.25640	0.46273	0.73020	0.02881	0.36731	25.34537	23.13135
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.52990	0.02881	0.02536	18.39292	13.84487
D		0.29200	0.22200	0.24300	0.82889	0.65820	0.02881	0.09356	22.84623	18.88025
C		0.19700	0.21176	0.24300	0.68083	0.71100	0.02881	0.18989	24.67893	21.42137
B		0.09800	0.20509	0.24300	0.48020	0.71340	0.02881	0.35117	24.76224	22.46465
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.43450	0.02881	0.00959	15.08157	10.38781
D		0.31000	0.21400	0.23330	0.85406	0.63720	0.02881	0.07872	22.11732	18.03093
C		0.20900	0.20200	0.23330	0.70126	0.70250	0.02881	0.17560	24.38389	21.02859
B		0.10500	0.19400	0.23330	0.49705	0.71340	0.02881	0.33596	24.76224	22.38401
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.61990	0.02881	0.06697	21.51683	17.33275
C		0.21800	0.19400	0.22600	0.71620	0.69620	0.02881	0.16537	24.16522	20.73843
B		0.11000	0.18500	0.22600	0.50875	0.71250	0.02881	0.32560	24.73100	22.29680
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.61030	0.02881	0.06166	21.18362	16.95471
C		0.22400	0.19070	0.22260	0.72599	0.69250	0.02881	0.15876	24.03679	20.56317
B		0.11300	0.18110	0.22260	0.51564	0.71060	0.02881	0.31958	24.66505	22.19788
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.56230	0.02881	0.04078	19.51753	15.10779
C		0.24200	0.17900	0.21100	0.75459	0.67290	0.02881	0.13986	23.35647	19.74598
B		0.12200	0.16700	0.21100	0.53578	0.70610	0.02881	0.30227	24.50885	21.94532
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.46290	0.02881	0.01453	16.06734	11.41971
C		0.27100	0.16820	0.19800	0.79853	0.64170	0.02881	0.11202	22.27352	18.45281
B		0.13700	0.15170	0.19800	0.56776	0.69870	0.02881	0.27570	24.25200	21.53543
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.62160	0.02881	0.09526	21.57584	17.62347
B		0.14100	0.14320	0.19100	0.57599	0.69210	0.02881	0.26904	24.02291	21.26697
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.59020	0.02881	0.07238	20.48594	16.34716
B		0.16000	0.13480	0.18360	0.61357	0.68060	0.02881	0.23949	23.62374	20.68799
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.46100	0.02881	0.01957	16.00139	11.40035
B		0.20400	0.11850	0.16700	0.69282	0.65820	0.02881	0.18146	22.84623	19.53130
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.64300	0.02881	0.16537	22.31864	18.89185
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.59440	0.02881	0.07792	20.63173	16.53875

TABLE 3.2 Analysis of Data for H - 2 Series.

H - 3 SERIES d = 20.25 cm. slope = 0.00000 Q = 30.209 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.69180	0.04064	0.00898	17.02264	12.32314
E		0.33100	0.25810	0.27190	0.88251	0.88650	0.04064	0.06241	21.81348	17.59095
D		0.25100	0.24900	0.27190	0.76850	0.92560	0.04064	0.13090	22.77559	19.09857
C		0.16800	0.23800	0.27190	0.62872	0.94080	0.04064	0.22795	23.14961	20.14136
B		0.08400	0.23797	0.27190	0.44458	0.95230	0.04064	0.38449	23.43258	21.30542
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.86620	0.04064	0.05281	21.31398	17.00932
D		0.25900	0.24250	0.26500	0.78065	0.91870	0.04064	0.12319	22.60581	18.87065
C		0.17400	0.23460	0.26500	0.63985	0.93950	0.04064	0.21962	23.11762	20.05612
B		0.08700	0.22690	0.26500	0.45244	0.95180	0.04064	0.37699	23.42028	21.25547
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.84040	0.04064	0.03599	20.67913	16.22685
D		0.27100	0.23410	0.25640	0.79853	0.91590	0.04064	0.11202	22.53691	18.71620
C		0.18200	0.22560	0.25640	0.65440	0.93910	0.04064	0.20890	23.10778	19.97669
B		0.09100	0.22040	0.25640	0.46273	0.94670	0.04064	0.36731	23.29478	21.08077
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.76970	0.04064	0.02536	18.93947	14.39142
D		0.29200	0.22200	0.24300	0.82889	0.93540	0.04064	0.09356	23.01673	19.05075
C		0.19700	0.21176	0.24300	0.68083	0.93630	0.04064	0.18989	23.03888	19.78132
B		0.09800	0.20509	0.24300	0.48020	0.93460	0.04064	0.35117	22.99705	20.69946
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.67900	0.04064	0.00959	16.70768	12.01392
D		0.31000	0.21400	0.23330	0.85406	0.88470	0.04064	0.07872	21.76919	17.68280
C		0.20900	0.20200	0.23330	0.70126	0.92850	0.04064	0.17560	22.84695	19.49164
B		0.10500	0.19400	0.23330	0.49705	0.93350	0.04064	0.33596	22.96998	20.59175
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.85970	0.04064	0.06697	21.15404	16.96995
C		0.21800	0.19400	0.22600	0.71620	0.92050	0.04064	0.16537	22.65010	19.22331
B		0.11000	0.18500	0.22600	0.50875	0.92790	0.04064	0.32560	22.83219	20.39799
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.84980	0.04064	0.06166	20.91043	16.68152
C		0.22400	0.19070	0.22260	0.72599	0.91590	0.04064	0.15876	22.53691	19.06328
B		0.11300	0.18110	0.22260	0.51564	0.92600	0.04064	0.31958	22.78543	20.31827
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.79960	0.04064	0.04078	19.67520	15.26546
C		0.24200	0.17900	0.21100	0.75459	0.89990	0.04064	0.13986	22.14321	18.53271
B		0.12200	0.16700	0.21100	0.53578	0.92330	0.04064	0.30227	22.71900	20.15546
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.68510	0.04064	0.01453	16.85778	12.21015
C		0.27100	0.16820	0.19800	0.79853	0.88410	0.04064	0.11202	21.75443	17.93372
B		0.13700	0.15170	0.19800	0.56776	0.91840	0.04064	0.27570	22.59843	19.88186
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.83080	0.04064	0.09526	20.44291	16.49054
B		0.14100	0.14320	0.19100	0.57599	0.91370	0.04064	0.26904	22.48278	19.72684
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.85480	0.04064	0.07238	21.03346	16.89468
B		0.16000	0.13480	0.18360	0.61357	0.90550	0.04064	0.23949	22.28100	19.34525
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.71150	0.04064	0.01957	17.50738	12.90635
B		0.20400	0.11850	0.16700	0.69282	0.89360	0.04064	0.18146	21.98819	18.67326
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.88200	0.04064	0.16537	21.70276	18.27597
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.82380	0.04064	0.07792	20.27067	16.17769

TABLE 3.3 Analysis of Data for H - 3 Series.

H - 6 SERIES d = 25.19 cm. slope = 0.00000 Q = 45.096 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	0.95670	0.04632	0.03463	20.65504	16.19067
E		0.29900	0.28020	0.29640	0.83877	1.03200	0.04632	0.08769	22.28075	18.26752
D		0.22600	0.27340	0.29640	0.72922	1.06000	0.04632	0.15659	22.88527	19.39617
C		0.15100	0.26840	0.29640	0.59607	1.07130	0.04632	0.25308	23.12924	20.27725
B		0.07600	0.26540	0.29640	0.42288	1.06300	0.04632	0.40560	22.95004	20.92671
F	55.34000	0.38600	0.27930	0.28510	0.95301	0.90310	0.04632	0.02406	19.49782	14.93794
E		0.31200	0.26970	0.28510	0.85681	1.02850	0.04632	0.07712	22.20519	18.10564
D		0.23600	0.26200	0.28510	0.74518	1.06300	0.04632	0.14601	22.95004	19.38458
C		0.15800	0.25630	0.28510	0.60973	1.06500	0.04632	0.24245	22.99322	20.07588
B		0.08000	0.25280	0.28510	0.43386	1.06200	0.04632	0.39484	22.92845	20.85256
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.79080	0.04632	0.00898	17.07328	12.37378
E		0.33100	0.25810	0.27190	0.88251	1.01040	0.04632	0.06241	21.81441	17.59188
D		0.25100	0.24900	0.27190	0.76850	1.05900	0.04632	0.13090	22.86368	19.18666
C		0.16800	0.23800	0.27190	0.62872	1.06230	0.04632	0.22795	22.93493	19.92668
B		0.08400	0.23797	0.27190	0.44458	1.05900	0.04632	0.38449	22.86368	20.73653
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.99610	0.04632	0.05281	21.50568	17.20102
D		0.25900	0.24250	0.26500	0.78065	1.04400	0.04632	0.12319	22.53983	18.80467
C		0.17400	0.23460	0.26500	0.63985	1.06140	0.04632	0.21962	22.91550	19.85400
B		0.08700	0.22690	0.26500	0.45244	1.05900	0.04632	0.37699	22.86368	20.69888
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.96950	0.04632	0.03599	20.93139	16.47910
D		0.27100	0.23410	0.25640	0.79853	1.03920	0.04632	0.11202	22.43620	18.61549
C		0.18200	0.22560	0.25640	0.65440	1.05920	0.04632	0.20890	22.86800	19.73691
B		0.09100	0.22040	0.25640	0.46273	1.05820	0.04632	0.36731	22.84641	20.63240
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.90170	0.04632	0.02536	19.46759	14.91955
D		0.29200	0.22200	0.24300	0.82889	1.03460	0.04632	0.09356	22.33689	18.37091
C		0.19700	0.21176	0.24300	0.68083	1.05750	0.04632	0.18989	22.83130	19.57374
B		0.09800	0.20509	0.24300	0.48020	1.05900	0.04632	0.35117	22.86368	20.56609
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.77450	0.04632	0.00959	16.72136	12.02760
D		0.31000	0.21400	0.23330	0.85406	1.01640	0.04632	0.07872	21.94395	17.85756
C		0.20900	0.20200	0.23330	0.70126	1.05090	0.04632	0.17560	22.68880	19.33350
B		0.10500	0.19400	0.23330	0.49705	1.05090	0.04632	0.33596	22.68880	20.31057
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.00010	0.04632	0.06697	21.59204	17.40795
C		0.21800	0.19400	0.22600	0.71620	1.05040	0.04632	0.16537	22.67801	19.25122
B		0.11000	0.18500	0.22600	0.50875	1.05090	0.04632	0.32560	22.68880	20.25461
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.99070	0.04632	0.06166	21.38909	17.16018
C		0.22400	0.19070	0.22260	0.72599	1.04840	0.04632	0.15876	22.63483	19.16120
B		0.11300	0.18110	0.22260	0.51564	1.05070	0.04632	0.31958	22.68449	20.21732
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.93280	0.04632	0.04078	20.13904	15.72930
C		0.24200	0.17900	0.21100	0.75459	1.03370	0.04632	0.13986	22.31746	18.70696
B		0.12200	0.16700	0.21100	0.53578	1.04870	0.04632	0.30227	22.64131	20.07777
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.82570	0.04632	0.01453	17.82676	13.17913
C		0.27100	0.16820	0.19800	0.79853	1.01060	0.04632	0.11202	21.81873	17.99802
B		0.13700	0.15170	0.19800	0.56776	1.04440	0.04632	0.27570	22.54847	19.83191
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.99710	0.04632	0.09526	21.52727	17.57489
B		0.14100	0.14320	0.19100	0.57599	1.04030	0.04632	0.26904	22.45995	19.70402
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.97980	0.04632	0.07238	21.15376	17.01498
B		0.16000	0.13480	0.18360	0.61357	1.03270	0.04632	0.23949	22.29587	19.36012
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.82910	0.04632	0.01957	17.90017	13.29913
B		0.20400	0.11850	0.16700	0.69282	1.00960	0.04632	0.18146	21.79714	18.48221
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.00280	0.04632	0.16537	21.65033	18.22354
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.94290	0.04632	0.07792	20.35710	16.26412

TABLE 3.4 Analysis of Data for H - 6 Series.

M1 - 3 SERIES d = 10.30 cm. slope = 0.00295 Q = 9.808 lt/sec.

SECTION	η	τ	h_τ (m.)	h_η (m.)	$(\tau/\tau_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\tau/\tau_0)^{0.5}}{1+(\tau/\tau_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\tau}{\tau_0}}$
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.64740	0.03593	0.02536	18.01837	13.47032
D		0.29200	0.22200	0.24300	0.82889	0.76290	0.03593	0.09356	21.23295	17.26697
C		0.19700	0.21176	0.24300	0.68083	0.81400	0.03593	0.18989	22.65516	19.39760
B		0.09800	0.20509	0.24300	0.48020	0.83970	0.03593	0.35117	23.37044	21.07285
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.57130	0.03593	0.00959	15.90036	11.20660
D		0.31000	0.21400	0.23330	0.85406	0.76150	0.03593	0.07872	21.19399	17.10760
C		0.20900	0.20200	0.23330	0.70126	0.81400	0.03593	0.17560	22.65516	19.29985
B		0.10500	0.19400	0.23330	0.49705	0.83970	0.03593	0.33596	23.37044	20.99221
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.74000	0.03593	0.06697	20.59560	16.41151
C		0.21800	0.19400	0.22600	0.71620	0.81400	0.03593	0.16537	22.65516	19.22837
B		0.11000	0.18500	0.22600	0.50875	0.83660	0.03593	0.32560	23.28416	20.84997
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.72630	0.03593	0.06166	20.21431	15.98540
C		0.22400	0.19070	0.22260	0.72599	0.80760	0.03593	0.15876	22.47704	19.00341
B		0.11300	0.18110	0.22260	0.51564	0.83360	0.03593	0.31958	23.20067	20.73350
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.67620	0.03593	0.04078	18.81993	14.41019
C		0.24200	0.17900	0.21100	0.75459	0.77210	0.03593	0.13986	21.48901	17.87851
B		0.12200	0.16700	0.21100	0.53578	0.82330	0.03593	0.30227	22.91400	20.35046
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.57100	0.03593	0.01453	15.89201	11.24438
C		0.27100	0.16820	0.19800	0.79853	0.73730	0.03593	0.11202	20.52046	16.69975
B		0.13700	0.15170	0.19800	0.56776	0.80080	0.03593	0.27570	22.28778	19.57122
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.72340	0.03593	0.09526	20.13359	16.18122
B		0.14100	0.14320	0.19100	0.57599	0.79240	0.03593	0.26904	22.05399	19.29806
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.70200	0.03593	0.07238	19.53799	15.39921
B		0.16000	0.13480	0.18360	0.61357	0.78860	0.03593	0.23949	21.94823	19.01248
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.59150	0.03593	0.01957	16.46257	11.86153
B		0.20400	0.11850	0.16700	0.69282	0.77120	0.03593	0.18146	21.46396	18.14903
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.75770	0.03593	0.16537	21.08823	17.66144
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.70550	0.03593	0.07792	19.63540	15.54242

TABLE 3.5 Analysis of Data for M1 - 3 Series.

M1 - 4 SERIES d = 10.07 cm. slope = 0.00295 Q = 9.5570 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.62570	0.03352	0.02536	18.66647	14.11842
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.52612	0.03352	0.00959	15.69570	11.00194
D		0.31000	0.21400	0.23330	0.85406	0.74763	0.03352	0.07872	22.30400	18.21760
C		0.20900	0.20200	0.23330	0.70126	0.76121	0.03352	0.17560	22.70913	19.35382
B		0.10500	0.19400	0.23330	0.49705	0.80612	0.03352	0.33596	24.04893	21.67070
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.73295	0.03352	0.06697	21.86605	17.68196
C		0.21800	0.19400	0.22600	0.71620	0.77009	0.03352	0.16537	22.97405	19.54726
B		0.11000	0.18500	0.22600	0.50875	0.81400	0.03352	0.32560	24.28401	21.84981
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.72280	0.03352	0.06166	21.56325	17.33434
C		0.22400	0.19070	0.22260	0.72599	0.77008	0.03352	0.15876	22.97375	19.50012
B		0.11300	0.18110	0.22260	0.51564	0.81452	0.03352	0.31958	24.29952	21.83236
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.65624	0.03352	0.04078	19.57757	15.16783
C		0.24200	0.17900	0.21100	0.75459	0.76479	0.03352	0.13986	22.81593	19.20543
B		0.12200	0.16700	0.21100	0.53578	0.81192	0.03352	0.30227	24.22196	21.65842
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.57078	0.03352	0.01453	17.02804	12.38041
C		0.27100	0.16820	0.19800	0.79853	0.75585	0.03352	0.11202	22.54922	18.72852
B		0.13700	0.15170	0.19800	0.56776	0.80509	0.03352	0.27570	24.01820	21.30164
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.74591	0.03352	0.09526	22.25268	18.30031
B		0.14100	0.14320	0.19100	0.57599	0.80324	0.03352	0.26904	23.96301	21.20707
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.71990	0.03352	0.07238	21.47673	17.33795
B		0.16000	0.13480	0.18360	0.61357	0.80142	0.03352	0.23949	23.90871	20.97296
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.57340	0.03352	0.01957	17.10621	12.50517
B		0.20400	0.11850	0.16700	0.69282	0.78480	0.03352	0.18146	23.41289	20.09796
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.76812	0.03352	0.16537	22.91527	19.48848
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.69234	0.03352	0.07792	20.65453	16.56156

TABLE 3.6 Analysis of Data for M1 - 4 Series.

M1 - 5 SERIES d = 13.82 cm. slope = 0.00295 Q = 19.295 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.87270	0.04077	0.05281	21.40545	17.10079
C		0.17400	0.23460	0.26500	0.63985	0.94270	0.04077	0.21962	23.12239	20.06090
B		0.08700	0.22690	0.26500	0.45244	0.94900	0.04077	0.37699	23.27692	21.11211
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.85800	0.04077	0.03599	21.04489	16.59260
D		0.27100	0.23410	0.25640	0.79853	0.92770	0.04077	0.11202	22.75448	18.93377
C		0.18200	0.22560	0.25640	0.65440	0.94400	0.04077	0.20890	23.15428	20.02319
B		0.09100	0.22040	0.25640	0.46273	0.95080	0.04077	0.36731	23.32107	21.10706
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.82160	0.04077	0.02536	20.15207	15.60403
D		0.29200	0.22200	0.24300	0.82889	0.93540	0.04077	0.09356	22.94334	18.97736
C		0.19700	0.21176	0.24300	0.68083	0.95120	0.04077	0.18989	23.33088	20.07332
B		0.09800	0.20509	0.24300	0.48020	0.95850	0.04077	0.35117	23.50993	21.21235
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.74080	0.04077	0.00959	18.17022	13.47646
D		0.31000	0.21400	0.23330	0.85406	0.92260	0.04077	0.07872	22.62938	18.54299
C		0.20900	0.20200	0.23330	0.70126	0.95610	0.04077	0.17560	23.45107	20.09576
B		0.10500	0.19400	0.23330	0.49705	0.95850	0.04077	0.33596	23.50993	21.13170
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.93160	0.04077	0.06697	22.85013	18.66605
C		0.21800	0.19400	0.22600	0.71620	0.95920	0.04077	0.16537	23.52710	20.10031
B		0.11000	0.18500	0.22600	0.50875	0.96010	0.04077	0.32560	23.54918	21.11498
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.90900	0.04077	0.06166	22.29581	18.06690
C		0.22400	0.19070	0.22260	0.72599	0.96100	0.04077	0.15876	23.57125	20.09763
B		0.11300	0.18110	0.22260	0.51564	0.96080	0.04077	0.31958	23.56635	21.09918
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.87090	0.04077	0.04078	21.36130	16.95156
C		0.24200	0.17900	0.21100	0.75459	0.95650	0.04077	0.13986	23.46088	19.85038
B		0.12200	0.16700	0.21100	0.53578	0.96390	0.04077	0.30227	23.64238	21.07885
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.75510	0.04077	0.01453	18.52097	13.87334
C		0.27100	0.16820	0.19800	0.79853	0.94800	0.04077	0.11202	23.25239	19.43168
B		0.13700	0.15170	0.19800	0.56776	0.96580	0.04077	0.27570	23.68899	20.97243
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.94220	0.04077	0.09526	23.11013	19.15775
B		0.14100	0.14320	0.19100	0.57599	0.96400	0.04077	0.26904	23.64484	20.88890
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.92170	0.04077	0.07238	22.60731	18.46852
B		0.16000	0.13480	0.18360	0.61357	0.96080	0.04077	0.23949	23.56635	20.63060
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.75350	0.04077	0.01957	18.48173	13.88069
B		0.20400	0.11850	0.16700	0.69282	0.94900	0.04077	0.18146	23.27692	19.96199
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.94180	0.04077	0.16537	23.10032	19.67353
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.87160	0.04077	0.07792	21.37846	17.28549

TABLE 3.7 Analysis of Data for M1 - 5 Series.

M1 - 6 SERIES   d = 19.50 cm.   slope = 0.00295   Q = 31.575 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	0.87140	0.04389	0.03463	19.85418	15.38981
E		0.29900	0.28020	0.29640	0.83877	0.95790	0.04389	0.08769	21.82502	17.81178
D		0.22600	0.27340	0.29640	0.72922	0.97980	0.04389	0.15659	22.32399	18.83489
C		0.15100	0.26840	0.29640	0.59607	0.99360	0.04389	0.25308	22.63841	19.78643
B		0.07600	0.26540	0.29640	0.42288	0.99810	0.04389	0.40560	22.74094	20.71762
F	55.34000	0.38600	0.27930	0.28510	0.95301	0.74880	0.04389	0.02406	17.06083	12.50096
E		0.31200	0.26970	0.28510	0.85681	0.93740	0.04389	0.07712	21.35794	17.25839
D		0.23600	0.26200	0.28510	0.74518	0.97110	0.04389	0.14601	22.12577	18.56031
C		0.15800	0.25630	0.28510	0.60973	0.98540	0.04389	0.24245	22.45158	19.53424
B		0.08000	0.25280	0.28510	0.43386	0.99690	0.04389	0.39484	22.71360	20.63771
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.66450	0.04389	0.00898	15.14012	10.44063
E		0.33100	0.25810	0.27190	0.88251	0.89470	0.04389	0.06241	20.38505	16.16252
D		0.25100	0.24900	0.27190	0.76850	0.96600	0.04389	0.13090	22.00957	18.33255
C		0.16800	0.23800	0.27190	0.62872	0.97640	0.04389	0.22795	22.24653	19.23828
B		0.08400	0.23797	0.27190	0.44458	0.98520	0.04389	0.38449	22.44703	20.31987
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.86450	0.04389	0.05281	19.69697	15.39231
D		0.25900	0.24250	0.26500	0.78065	0.95940	0.04389	0.12319	21.85919	18.12403
C		0.17400	0.23460	0.26500	0.63985	0.97550	0.04389	0.21962	22.22602	19.16452
B		0.08700	0.22690	0.26500	0.45244	0.98730	0.04389	0.37699	22.49487	20.33007
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.85430	0.04389	0.03599	19.46457	15.01228
D		0.27100	0.23410	0.25640	0.79853	0.95340	0.04389	0.11202	21.72249	17.90178
C		0.18200	0.22560	0.25640	0.65440	1.00160	0.04389	0.20890	22.82069	19.68960
B		0.09100	0.22040	0.25640	0.46273	0.99060	0.04389	0.36731	22.57006	20.35605
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.82090	0.04389	0.02536	18.70358	14.15553
D		0.29200	0.22200	0.24300	0.82889	0.95340	0.04389	0.09356	21.72249	17.75651
C		0.19700	0.21176	0.24300	0.68083	0.97870	0.04389	0.18989	22.29893	19.04137
B		0.09800	0.20509	0.24300	0.48020	0.99700	0.04389	0.35117	22.71588	20.41829
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.70880	0.04389	0.00959	16.14946	11.45570
D		0.31000	0.21400	0.23330	0.85406	0.96480	0.04389	0.07872	21.98223	17.89584
C		0.20900	0.20200	0.23330	0.70126	0.97850	0.04389	0.17560	22.29437	18.93906
B		0.10500	0.19400	0.23330	0.49705	0.99700	0.04389	0.33596	22.71588	20.33765
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.93090	0.04389	0.06697	21.20984	17.02575
C		0.21800	0.19400	0.22600	0.71620	0.97700	0.04389	0.16537	22.26020	18.83341
B		0.11000	0.18500	0.22600	0.50875	0.99700	0.04389	0.32560	22.71588	20.28168
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.92350	0.04389	0.06166	21.04124	16.81233
C		0.22400	0.19070	0.22260	0.72599	0.97620	0.04389	0.15876	22.24197	18.76834
B		0.11300	0.18110	0.22260	0.51564	0.99680	0.04389	0.31958	22.71132	20.24416
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.86730	0.04389	0.04078	19.76077	15.35103
C		0.24200	0.17900	0.21100	0.75459	0.96960	0.04389	0.13986	22.09159	18.48110
B		0.12200	0.16700	0.21100	0.53578	0.99460	0.04389	0.30227	22.66120	20.09766
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.74760	0.04389	0.01453	17.03349	12.38586
C		0.27100	0.16820	0.19800	0.79853	0.95340	0.04389	0.11202	21.72249	17.90178
B		0.13700	0.15170	0.19800	0.56776	0.99040	0.04389	0.27570	22.56550	19.84894
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.93920	0.04389	0.09526	21.39895	17.44658
B		0.14100	0.14320	0.19100	0.57599	0.98580	0.04389	0.26904	22.46070	19.70476
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.91250	0.04389	0.07238	20.79061	16.65183
B		0.16000	0.13480	0.18360	0.61357	0.97780	0.04389	0.23949	22.27842	19.34267
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.76520	0.04389	0.01957	17.43450	12.83346
B		0.20400	0.11850	0.16700	0.69282	0.96010	0.04389	0.18146	21.87514	18.56021
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.94840	0.04389	0.16537	21.60857	18.18178
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.87130	0.04389	0.07792	19.85190	15.75892

TABLE 3.8 Analysis of Data for M1 - 6 Series.

M1 - 7 SERIES d = 25.25 cm. slope = 0.00295 Q = 52.906 lt/sec.

SECTION	η	ξ	h_{ξ} (m.)	h_{η} (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_{τ} (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	0.98800	0.04800	0.03463	20.58333	16.11896
E		0.29900	0.28020	0.29640	0.83877	1.08850	0.04800	0.08769	22.67708	18.66385
D		0.22600	0.27340	0.29640	0.72922	1.12150	0.04800	0.15659	23.36458	19.87548
C		0.15100	0.26840	0.29640	0.59607	1.15300	0.04800	0.25308	24.02083	21.16885
B		0.07600	0.26540	0.29640	0.42288	1.14380	0.04800	0.40560	23.82917	21.80584
F	55.34000	0.38600	0.27930	0.28510	0.95301	0.88860	0.04800	0.02406	18.51250	13.95263
E		0.31200	0.26970	0.28510	0.85681	1.04340	0.04800	0.07712	21.73750	17.63795
D		0.23600	0.26200	0.28510	0.74518	1.08280	0.04800	0.14601	22.55833	18.99288
C		0.15800	0.25630	0.28510	0.60973	1.16370	0.04800	0.24245	24.24375	21.32640
B		0.08000	0.25280	0.28510	0.43386	1.13640	0.04800	0.39484	23.67500	21.59911
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.76110	0.04800	0.00898	15.85625	11.15676
E		0.33100	0.25810	0.27190	0.88251	1.00110	0.04800	0.06241	20.85625	16.63372
D		0.25100	0.24900	0.27190	0.76850	1.06660	0.04800	0.13090	22.22083	18.54381
C		0.16800	0.23800	0.27190	0.62872	1.11690	0.04800	0.22795	23.26875	20.26050
B		0.08400	0.23797	0.27190	0.44458	1.12420	0.04800	0.38449	23.42083	21.29368
E	48.30000	0.34400	0.25240	0.26500	0.89967	0.98230	0.04800	0.05281	20.46458	16.15993
D		0.25900	0.24250	0.26500	0.78065	1.06260	0.04800	0.12319	22.13750	18.40234
C		0.17400	0.23460	0.26500	0.63985	1.10840	0.04800	0.21962	23.09167	20.03017
B		0.08700	0.22690	0.26500	0.45244	1.12230	0.04800	0.37699	23.38125	21.21644
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.95960	0.04800	0.03599	19.99167	15.53938
D		0.27100	0.23410	0.25640	0.79853	1.02400	0.04800	0.11202	21.33333	17.51262
C		0.18200	0.22560	0.25640	0.65440	1.10630	0.04800	0.20890	23.04792	19.91683
B		0.09100	0.22040	0.25640	0.46273	1.12040	0.04800	0.36731	23.34167	21.12765
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.89890	0.04800	0.02536	18.72708	14.17904
D		0.29200	0.22200	0.24300	0.82889	1.04280	0.04800	0.09356	21.72500	17.75902
C		0.19700	0.21176	0.24300	0.68083	1.10320	0.04800	0.18989	22.98333	19.72577
B		0.09800	0.20509	0.24300	0.48020	1.11750	0.04800	0.35117	23.28125	20.98366
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.79220	0.04800	0.00959	16.50417	11.81041
D		0.31000	0.21400	0.23330	0.85406	1.02840	0.04800	0.07872	21.42500	17.33861
C		0.20900	0.20200	0.23330	0.70126	1.10450	0.04800	0.17560	23.01042	19.65511
B		0.10500	0.19400	0.23330	0.49705	1.11330	0.04800	0.33596	23.19375	20.81552
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.01620	0.04800	0.06697	21.17083	16.98674
C		0.21800	0.19400	0.22600	0.71620	1.10720	0.04800	0.16537	23.06667	19.63988
B		0.11000	0.18500	0.22600	0.50875	1.11070	0.04800	0.32560	23.13958	20.70539
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.00930	0.04800	0.06166	21.02708	16.79817
C		0.22400	0.19070	0.22260	0.72599	1.10880	0.04800	0.15876	23.10000	19.62637
B		0.11300	0.18110	0.22260	0.51564	1.10950	0.04800	0.31958	23.11458	20.64742
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.92930	0.04800	0.04078	19.36042	14.95068
C		0.24200	0.17900	0.21100	0.75459	1.08380	0.04800	0.13986	22.57917	18.96867
B		0.12200	0.16700	0.21100	0.53578	1.10570	0.04800	0.30227	23.03542	20.47188
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.81090	0.04800	0.01453	16.89375	12.24612
C		0.27100	0.16820	0.19800	0.79853	1.05500	0.04800	0.11202	21.97917	18.15846
B		0.13700	0.15170	0.19800	0.56776	1.09930	0.04800	0.27570	22.90208	20.18552
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.04630	0.04800	0.09526	21.79792	17.84554
B		0.14100	0.14320	0.19100	0.57599	1.09520	0.04800	0.26904	22.81667	20.06073
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.02220	0.04800	0.07238	21.29583	17.15705
B		0.16000	0.13480	0.18360	0.61357	1.08700	0.04800	0.23949	22.64583	19.71008
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.84090	0.04800	0.01957	17.51875	12.91772
B		0.20400	0.11850	0.16700	0.69282	1.06900	0.04800	0.18146	22.27083	18.95590
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.05390	0.04800	0.16537	21.95625	18.52946
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.98370	0.04800	0.07792	20.49375	16.40077

TABLE 3.9 Analysis of Data for M1 - 7 Series.

M2 - 3 SERIES d = 10.00 cm. slope = 0.00450 Q = 11.167 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.86690	0.03984	0.06697	21.75954	17.57545
C		0.21800	0.19400	0.22600	0.71620	0.97550	0.03984	0.16537	24.48544	21.05865
B		0.11000	0.18500	0.22600	0.50875	1.00396	0.03984	0.32560	25.19980	22.76560
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.87930	0.03984	0.06166	22.07078	17.84187
C		0.22400	0.19070	0.22260	0.72599	0.97470	0.03984	0.15876	24.46536	20.99173
B		0.11300	0.18110	0.22260	0.51564	1.00372	0.03984	0.31958	25.19378	22.72661
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.78861	0.03984	0.04078	19.79443	15.38469
C		0.24200	0.17900	0.21100	0.75459	0.96808	0.03984	0.13986	24.29920	20.68870
B		0.12200	0.16700	0.21100	0.53578	0.99956	0.03984	0.30227	25.08936	22.52582
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.69496	0.03984	0.01453	17.44378	12.79615
C		0.27100	0.16820	0.19800	0.79853	0.94550	0.03984	0.11202	23.73243	19.91172
B		0.13700	0.15170	0.19800	0.56776	0.99098	0.03984	0.27570	24.87400	22.15743
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.92477	0.03984	0.09526	23.21210	19.25972
B		0.14100	0.14320	0.19100	0.57599	0.98711	0.03984	0.26904	24.77686	22.02092
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.86960	0.03984	0.07238	21.82731	17.68852
B		0.16000	0.13480	0.18360	0.61357	0.97808	0.03984	0.23949	24.55020	21.61445
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.65672	0.03984	0.01957	16.48394	11.88290
B		0.20400	0.11850	0.16700	0.69282	0.95790	0.03984	0.18146	24.04367	20.72874
B	17.30000	0.21800	0.11300	0.16200	0.71620	0.83428	0.03984	0.16537	20.94076	17.51397
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.80057	0.03984	0.07792	20.09463	16.00165

TABLE 3.10 Analysis of Data for M2 - 3 Series .

M2 - 5 SERIES d = 15.44 cm. slope = 0.00450 Q = 25.753 lt/sec.

SECTION	τ	ζ	h_ζ (m.)	h_τ (m.)	$(\zeta/\zeta_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\zeta/\zeta_o)^{0.5}}{1+(\zeta/\zeta_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\zeta}{\zeta_o}}$
F	55.34000	0.38600	0.27930	0.28510	0.95301	0.82440	0.04534	0.02406	18.18262	13.62275
E		0.31200	0.26970	0.28510	0.85681	1.03572	0.04534	0.07712	22.84341	18.74385
D		0.23600	0.26200	0.28510	0.74518	1.04690	0.04534	0.14601	23.08999	19.52453
C		0.15800	0.25630	0.28510	0.60973	1.09957	0.04534	0.24245	24.25165	21.33431
B		0.08000	0.25280	0.28510	0.43386	1.11568	0.04534	0.39484	24.60697	22.53108
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.71046	0.04534	0.00898	15.66961	10.97011
E		0.33100	0.25810	0.27190	0.88251	1.02948	0.04534	0.06241	22.70578	18.48324
D		0.25100	0.24900	0.27190	0.76850	1.07801	0.04534	0.13090	23.77614	20.09911
C		0.16800	0.23800	0.27190	0.62872	1.10182	0.04534	0.22795	24.30128	21.29303
B		0.08400	0.23797	0.27190	0.44458	1.07980	0.04534	0.38449	23.81562	21.68846
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.01022	0.04534	0.05281	22.28099	17.97633
D		0.25900	0.24250	0.26500	0.78065	1.07011	0.04534	0.12319	23.60190	19.86674
C		0.17400	0.23460	0.26500	0.63985	1.09444	0.04534	0.21962	24.13851	21.07701
B		0.08700	0.22690	0.26500	0.45244	1.10413	0.04534	0.37699	24.35223	22.18742
E	45.60000	0.36800	0.24710	0.25640	0.93053	0.96388	0.04534	0.03599	21.25893	16.80665
D		0.27100	0.23410	0.25640	0.79853	1.05813	0.04534	0.11202	23.33767	19.51696
C		0.18200	0.22560	0.25640	0.65440	1.08377	0.04534	0.20890	23.90318	20.77209
B		0.09100	0.22040	0.25640	0.46273	1.09930	0.04534	0.36731	24.24570	22.03169
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.85916	0.04534	0.02536	18.94927	14.40123
D		0.29200	0.22200	0.24300	0.82889	1.03050	0.04534	0.09356	22.72828	18.76229
C		0.19700	0.21176	0.24300	0.68083	1.07688	0.04534	0.18989	23.75121	20.49365
B		0.09800	0.20509	0.24300	0.48020	1.09060	0.04534	0.35117	24.05382	21.75623
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.73882	0.04534	0.00959	16.29510	11.60134
D		0.31000	0.21400	0.23330	0.85406	1.01050	0.04534	0.07872	22.28716	18.20077
C		0.20900	0.20200	0.23330	0.70126	1.06770	0.04534	0.17560	23.54874	20.19343
B		0.10500	0.19400	0.23330	0.49705	1.08631	0.04534	0.33596	23.95920	21.58097
D	36.40000	0.32500	0.20800	0.22600	0.87447	0.99050	0.04534	0.06697	21.84605	17.66196
C		0.21800	0.19400	0.22600	0.71620	1.05810	0.04534	0.16537	23.33701	19.91022
B		0.11000	0.18500	0.22600	0.50875	1.08358	0.04534	0.32560	23.89899	21.46479
D	35.52000	0.33200	0.20570	0.22260	0.88384	0.97550	0.04534	0.06166	21.51522	17.28631
C		0.22400	0.19070	0.22260	0.72599	1.05450	0.04534	0.15876	23.25761	19.78398
B		0.11300	0.18110	0.22260	0.51564	1.08181	0.04534	0.31958	23.85995	21.39278
D	32.16000	0.36100	0.19800	0.21100	0.92164	0.87137	0.04534	0.04078	19.21857	14.80883
C		0.24200	0.17900	0.21100	0.75459	1.03559	0.04534	0.13986	22.84054	19.23004
B		0.12200	0.16700	0.21100	0.53578	1.07191	0.04534	0.30227	23.64160	21.07806
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.76220	0.04534	0.01453	16.81076	12.16313
C		0.27100	0.16820	0.19800	0.79853	1.00960	0.04534	0.11202	22.26731	18.44661
B		0.13700	0.15170	0.19800	0.56776	1.06004	0.04534	0.27570	23.37980	20.66324
C	26.50000	0.29000	0.16350	0.19100	0.82605	0.99220	0.04534	0.09526	21.88355	17.93117
B		0.14100	0.14320	0.19100	0.57599	1.05412	0.04534	0.26904	23.24923	20.49329
C	24.22000	0.31800	0.16000	0.18360	0.86501	0.94900	0.04534	0.07238	20.93075	16.79196
B		0.16000	0.13480	0.18360	0.61357	1.04376	0.04534	0.23949	23.02073	20.08498
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.80104	0.04534	0.01957	17.66740	13.06637
B		0.20400	0.11850	0.16700	0.69282	1.01390	0.04534	0.18146	22.36215	19.04722
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.00198	0.04534	0.16537	22.09925	18.67246
B	11.31000	0.31100	0.11380	0.14680	0.85543	0.91966	0.04534	0.07792	20.28363	16.19066

TABLE 3.11 Analysis of Data for M2 - 5 Series.

M2 - 6 SERIES d = 20.44 cm. slope = 0.00450 Q = 41.193 lt/sec.

SECTION	η	τ	h_τ (m.)	h_η (m.)	$(\tau/\tau_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\tau/\tau_o)^{0.5}}{1+(\tau/\tau_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\tau}{\tau_o}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	1.03190	0.04904	0.03463	21.04201	16.57764
E		0.29900	0.28020	0.29640	0.83877	1.15080	0.04904	0.08769	23.46656	19.45332
D		0.22600	0.27340	0.29640	0.72922	1.21230	0.04904	0.15659	24.72064	21.23154
C		0.15100	0.26840	0.29640	0.59607	1.22470	0.04904	0.25308	24.97349	22.12150
B		0.07600	0.26540	0.29640	0.42288	1.23830	0.04904	0.40560	25.25082	23.22749
F	55.34000	0.38600	0.27930	0.28510	0.95301	0.96230	0.04904	0.02406	19.62276	15.06288
E		0.31200	0.26970	0.28510	0.85681	1.15140	0.04904	0.07712	23.47879	19.37924
D		0.23600	0.26200	0.28510	0.74518	1.20710	0.04904	0.14601	24.61460	21.04914
C		0.15800	0.25630	0.28510	0.60973	1.22630	0.04904	0.24245	25.00612	22.08877
B		0.08000	0.25280	0.28510	0.43386	1.24090	0.04904	0.39484	25.30383	23.22794
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.88100	0.04904	0.00898	17.96493	13.26543
E		0.33100	0.25810	0.27190	0.88251	1.13920	0.04904	0.06241	23.23002	19.00748
D		0.25100	0.24900	0.27190	0.76850	1.20220	0.04904	0.13090	24.51468	20.83766
C		0.16800	0.23800	0.27190	0.62872	1.22630	0.04904	0.22795	25.00612	21.99787
B		0.08400	0.23797	0.27190	0.44458	1.23410	0.04904	0.38449	25.16517	23.03802
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.13040	0.04904	0.05281	23.05057	18.74591
D		0.25900	0.24250	0.26500	0.78065	1.20620	0.04904	0.12319	24.59625	20.86109
C		0.17400	0.23460	0.26500	0.63985	1.22630	0.04904	0.21962	25.00612	21.94462
B		0.08700	0.22690	0.26500	0.45244	1.23580	0.04904	0.37699	25.19984	23.03503
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.10900	0.04904	0.03599	22.61419	18.16191
D		0.27100	0.23410	0.25640	0.79853	1.20860	0.04904	0.11202	24.64519	20.82448
C		0.18200	0.22560	0.25640	0.65440	1.22630	0.04904	0.20890	25.00612	21.87503
B		0.09100	0.22040	0.25640	0.46273	1.23830	0.04904	0.36731	25.25082	23.03680
E	41.54000	0.38400	0.23600	0.24300	0.95054	0.93770	0.04904	0.02536	19.12113	14.57308
D		0.29200	0.22200	0.24300	0.82889	1.20180	0.04904	0.09356	24.50653	20.54054
C		0.19700	0.21176	0.24300	0.68083	1.22630	0.04904	0.18989	25.00612	21.74856
B		0.09800	0.20509	0.24300	0.48020	1.24350	0.04904	0.35117	25.35685	23.05926
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.93070	0.04904	0.00959	18.97838	14.28462
D		0.31000	0.21400	0.23330	0.85406	1.19890	0.04904	0.07872	24.44739	20.36100
C		0.20900	0.20200	0.23330	0.70126	1.22630	0.04904	0.17560	25.00612	21.65081
B		0.10500	0.19400	0.23330	0.49705	1.24350	0.04904	0.33596	25.35685	22.97862
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.18750	0.04904	0.06697	24.21493	20.03084
C		0.21800	0.19400	0.22600	0.71620	1.22630	0.04904	0.16537	25.00612	21.57933
B		0.11000	0.18500	0.22600	0.50875	1.24350	0.04904	0.32560	25.35685	22.92266
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.17680	0.04904	0.06166	23.99674	19.76783
C		0.22400	0.19070	0.22260	0.72599	1.22630	0.04904	0.15876	25.00612	21.53249
B		0.11300	0.18110	0.22260	0.51564	1.24330	0.04904	0.31958	25.35277	22.88561
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.14650	0.04904	0.04078	23.37887	18.96914
C		0.24200	0.17900	0.21100	0.75459	1.22630	0.04904	0.13986	25.00612	21.39562
B		0.12200	0.16700	0.21100	0.53578	1.24160	0.04904	0.30227	25.31811	22.75457
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.00620	0.04904	0.01453	20.51794	15.87032
C		0.27100	0.16820	0.19800	0.79853	1.21850	0.04904	0.11202	24.84706	21.02636
B		0.13700	0.15170	0.19800	0.56776	1.23930	0.04904	0.27570	25.27121	22.55465
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.20510	0.04904	0.09526	24.57382	20.62144
B		0.14100	0.14320	0.19100	0.57599	1.23590	0.04904	0.26904	25.20188	22.44594
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.15590	0.04904	0.07238	23.57055	19.43177
B		0.16000	0.13480	0.18360	0.61357	1.23110	0.04904	0.23949	25.10400	22.16825
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.97290	0.04904	0.01957	19.83891	15.23787
B		0.20400	0.11850	0.16700	0.69282	1.21580	0.04904	0.18146	24.79201	21.47708
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.20530	0.04904	0.16537	24.57790	21.15111
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.13880	0.04904	0.07792	23.22186	19.12888

TABLE 3.12 Analysis of Data for M2 - 6 Series.

S1 - 2 SERIES d = 10.30 cm. slope = 0.00923 Q = 15.808 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\dfrac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.04914	0.05053	0.02536	20.76272	16.21467
D		0.29200	0.22200	0.24300	0.82889	1.21580	0.05053	0.09356	24.06095	20.09497
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.91676	0.05053	0.00959	18.14289	13.44913
D		0.31000	0.21400	0.23330	0.85406	1.24476	0.05053	0.07872	24.63408	20.54769
B		0.10500	0.19400	0.23330	0.49705	1.24452	0.05053	0.33596	24.62933	22.25110
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.24260	0.05053	0.06697	24.59133	20.40724
C		0.21800	0.19400	0.22600	0.71620	1.24470	0.05053	0.16537	24.63289	21.20610
B		0.11000	0.18500	0.22600	0.50875	1.25166	0.05053	0.32560	24.77063	22.33644
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.23320	0.05053	0.06166	24.40530	20.17640
C		0.22400	0.19070	0.22260	0.72599	1.25595	0.05053	0.15876	24.85553	21.38190
B		0.11300	0.18110	0.22260	0.51564	1.25437	0.05053	0.31958	24.82426	22.35710
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.13712	0.05053	0.04078	22.50386	18.09412
C		0.24200	0.17900	0.21100	0.75459	1.26805	0.05053	0.13986	25.09499	21.48450
B		0.12200	0.16700	0.21100	0.53578	1.26007	0.05053	0.30227	24.93707	22.37353
D	28.45000	0.40100	0.19270	0.19800	0.97135	0.90564	0.05053	0.01453	17.92282	13.27519
C		0.27100	0.16820	0.19800	0.79853	1.25785	0.05053	0.11202	24.89313	21.07242
B		0.13700	0.15170	0.19800	0.56776	1.25853	0.05053	0.27570	24.90659	22.19003
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.24132	0.05053	0.09526	24.56600	20.61362
B		0.14100	0.14320	0.19100	0.57599	1.26138	0.05053	0.26904	24.96299	22.20706
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.19110	0.05053	0.07238	23.57214	19.43335
B		0.16000	0.13480	0.18360	0.61357	1.26637	0.05053	0.23949	25.06175	22.12599
C	19.16000	0.39300	0.15900	0.16700	0.96162	0.85460	0.05053	0.01957	16.91273	12.31169
B		0.20400	0.11850	0.16700	0.69282	1.26550	0.05053	0.18146	25.04453	21.72960
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.25942	0.05053	0.16537	24.92420	21.49741
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.15112	0.05053	0.07792	22.78092	18.68794

TABLE 3.13 Analysis of Data for S1 - 2 Series.

S1 - 3 SERIES d = 15.36 cm. slope = 0.00923 Q = 36.230 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
F	55.34000	0.38600	0.27930	0.28510	0.95301	1.03460	0.05379	0.02406	19.23406	14.67418
D		0.23600	0.26200	0.28510	0.74518	1.39790	0.05379	0.14601	25.98810	22.42264
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.96598	0.05379	0.00898	17.95836	13.25886
E		0.33100	0.25810	0.27190	0.88251	1.29308	0.05379	0.06241	24.03941	19.81688
D		0.25100	0.24900	0.27190	0.76850	1.40695	0.05379	0.13090	26.15635	22.47933
C		0.16800	0.23800	0.27190	0.62872	1.41140	0.05379	0.22795	26.23908	23.23083
B		0.08400	0.23797	0.27190	0.44458	1.43488	0.05379	0.38449	26.67559	24.54844
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.30342	0.05379	0.05281	24.23164	19.92699
D		0.25900	0.24250	0.26500	0.78065	1.39323	0.05379	0.12319	25.90128	22.16612
C		0.17400	0.23460	0.26500	0.63985	1.41050	0.05379	0.21962	26.22235	23.16085
B		0.08700	0.22690	0.26500	0.45244	1.43103	0.05379	0.37699	26.60402	24.43921
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.26768	0.05379	0.03599	23.56721	19.11492
D		0.27100	0.23410	0.25640	0.79853	1.37718	0.05379	0.11202	25.60290	21.78219
C		0.18200	0.22560	0.25640	0.65440	1.40720	0.05379	0.20890	26.16100	23.02991
B		0.09100	0.22040	0.25640	0.46273	1.42433	0.05379	0.36731	26.47946	24.26545
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.16282	0.05379	0.02536	21.61777	17.06973
D		0.29200	0.22200	0.24300	0.82889	1.36400	0.05379	0.09356	25.35787	21.39189
C		0.19700	0.21176	0.24300	0.68083	1.38635	0.05379	0.18989	25.77338	22.51582
B		0.09800	0.20509	0.24300	0.48020	1.41000	0.05379	0.35117	26.21305	23.91546
E	38.63000	0.40900	0.23000	0.23330	0.98100	1.01252	0.05379	0.00959	18.82357	14.12981
D		0.31000	0.21400	0.23330	0.85406	1.34136	0.05379	0.07872	24.93698	20.85058
C		0.20900	0.20200	0.23330	0.70126	1.37299	0.05379	0.17560	25.52500	22.16970
B		0.10500	0.19400	0.23330	0.49705	1.40401	0.05379	0.33596	26.10169	23.72346
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.28380	0.05379	0.06697	23.86689	19.68280
C		0.21800	0.19400	0.22600	0.71620	1.36431	0.05379	0.16537	25.36364	21.93685
B		0.11000	0.18500	0.22600	0.50875	1.40019	0.05379	0.32560	26.03067	23.59648
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.28380	0.05379	0.06166	23.86689	19.63798
C		0.22400	0.19070	0.22260	0.72599	1.36106	0.05379	0.15876	25.30322	21.82959
B		0.11300	0.18110	0.22260	0.51564	1.39828	0.05379	0.31958	25.99517	23.52800
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.17268	0.05379	0.04078	21.80108	17.39134
C		0.24200	0.17900	0.21100	0.75459	1.34431	0.05379	0.13986	24.99182	21.38132
B		0.12200	0.16700	0.21100	0.53578	1.39003	0.05379	0.30227	25.84179	23.27826
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.01408	0.05379	0.01453	18.85257	14.20495
C		0.27100	0.16820	0.19800	0.79853	1.31800	0.05379	0.11202	24.50270	20.68199
B		0.13700	0.15170	0.19800	0.56776	1.38095	0.05379	0.27570	25.67299	22.95643
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.29953	0.05379	0.09526	24.15932	20.20695
B		0.14100	0.14320	0.19100	0.57599	1.37764	0.05379	0.26904	25.61145	22.85552
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.26380	0.05379	0.07238	23.49507	19.35629
B		0.16000	0.13480	0.18360	0.61357	1.37185	0.05379	0.23949	25.50381	22.56806
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.06006	0.05379	0.01957	19.70738	15.10635
B		0.20400	0.11850	0.16700	0.69282	1.34840	0.05379	0.18146	25.06786	21.75293
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.29646	0.05379	0.16537	24.10225	20.67546
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.19997	0.05379	0.07792	22.30842	18.21544

TABLE 3.14 Analysis of Data for S1 - 3 Series.

S1 - 4 SERIES d = 16.55 cm. slope = 0.00923 Q = 36.282 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_0)^{0.5}}{1+(\xi/\xi_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_0}}$
F	55.34000	0.38600	0.27930	0.28510	0.95301	1.19860	0.05566	0.02406	21.53432	16.97444
D		0.23600	0.26200	0.28510	0.74518	1.40390	0.05566	0.14601	25.22278	21.65732
B		0.08000	0.25280	0.28510	0.43386	1.46540	0.05566	0.39484	26.32770	24.25181
F	50.65000	0.41000	0.26950	0.27190	0.98219	1.02400	0.05566	0.00898	18.39741	13.69792
E		0.33100	0.25810	0.27190	0.88251	1.40240	0.05566	0.06241	25.19583	20.97330
D		0.25100	0.24900	0.27190	0.76850	1.42990	0.05566	0.13090	25.68990	22.01288
B		0.08400	0.23797	0.27190	0.44458	1.45740	0.05566	0.38449	26.18397	24.05682
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.35930	0.05566	0.05281	24.42149	20.11683
D		0.25900	0.24250	0.26500	0.78065	1.44580	0.05566	0.12319	25.97557	22.24041
C		0.17400	0.23460	0.26500	0.63985	1.44510	0.05566	0.21962	25.96299	22.90149
B		0.08700	0.22690	0.26500	0.45244	1.43760	0.05566	0.37699	25.82824	23.66344
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.31660	0.05566	0.03599	23.65433	19.20204
D		0.27100	0.23410	0.25640	0.79853	1.42900	0.05566	0.11202	25.67373	21.85302
C		0.18200	0.22560	0.25640	0.65440	1.43210	0.05566	0.20890	25.72943	22.59834
B		0.09100	0.22040	0.25640	0.46273	1.43760	0.05566	0.36731	25.82824	23.61423
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.17480	0.05566	0.02536	21.10672	16.55867
D		0.29200	0.22200	0.24300	0.82889	1.40090	0.05566	0.09356	25.16888	21.20290
C		0.19700	0.21176	0.24300	0.68083	1.41520	0.05566	0.18989	25.42580	22.16824
B		0.09800	0.20509	0.24300	0.48020	1.42270	0.05566	0.35117	25.56055	23.26296
E	38.63000	0.40900	0.23000	0.23330	0.98100	0.95140	0.05566	0.00959	17.09307	12.39930
D		0.31000	0.21400	0.23330	0.85406	1.36890	0.05566	0.07872	24.59396	20.50757
C		0.20900	0.20200	0.23330	0.70126	1.40640	0.05566	0.17560	25.26770	21.91239
B		0.10500	0.19400	0.23330	0.49705	1.42270	0.05566	0.33596	25.56055	23.18232
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.32900	0.05566	0.06697	23.87711	19.69302
C		0.21800	0.19400	0.22600	0.71620	1.40210	0.05566	0.16537	25.19044	21.76365
B		0.11000	0.18500	0.22600	0.50875	1.41740	0.05566	0.32560	25.46533	23.03113
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.30340	0.05566	0.06166	23.41718	19.18827
C		0.22400	0.19070	0.22260	0.72599	1.39970	0.05566	0.15876	25.14732	21.67370
B		0.11300	0.18110	0.22260	0.51564	1.41530	0.05566	0.31958	25.42760	22.96043
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.22100	0.05566	0.04078	21.93676	17.52702
C		0.24200	0.17900	0.21100	0.75459	1.38150	0.05566	0.13986	24.82034	21.20984
B		0.12200	0.16700	0.21100	0.53578	1.40930	0.05566	0.30227	25.31980	22.75626
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.01190	0.05566	0.01453	18.18002	13.53239
C		0.27100	0.16820	0.19800	0.79853	1.35140	0.05566	0.11202	24.27955	20.45885
B		0.13700	0.15170	0.19800	0.56776	1.40190	0.05566	0.27570	25.18685	22.47029
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.33120	0.05566	0.09526	23.91664	19.96426
B		0.14100	0.14320	0.19100	0.57599	1.39780	0.05566	0.26904	25.11319	22.35725
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.29040	0.05566	0.07238	23.18361	19.04483
B		0.16000	0.13480	0.18360	0.61357	1.39070	0.05566	0.23949	24.98563	22.04988
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.05090	0.05566	0.01957	18.88070	14.27967
B		0.20400	0.11850	0.16700	0.69282	1.36400	0.05566	0.18146	24.50593	21.19100
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.34240	0.05566	0.16537	24.11786	20.69107
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.24700	0.05566	0.07792	22.40388	18.31090

TABLE 3.15 Analysis of Data for S1 - 4 Series.

S1 - 5 SERIES d = 20.22 cm. slope = 0.00923 Q = 53.819 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	1.23686	0.06230	0.03463	19.85329	15.38892
E		0.29900	0.28020	0.29640	0.83877	1.42580	0.06230	0.08769	22.88604	18.87280
D		0.22600	0.27340	0.29640	0.72922	1.49190	0.06230	0.15659	23.94703	20.45793
C		0.15100	0.26840	0.29640	0.59607	1.53410	0.06230	0.25308	24.62440	21.77241
B		0.07600	0.26540	0.29640	0.42288	1.56960	0.06230	0.40560	25.19422	23.17089
F	55.34000	0.38600	0.27930	0.28510	0.95301	1.12130	0.06230	0.02406	17.99839	13.43852
E		0.31200	0.26970	0.28510	0.85681	1.39940	0.06230	0.07712	22.46228	18.36273
D		0.23600	0.26200	0.28510	0.74518	1.47760	0.06230	0.14601	23.71750	20.15204
C		0.15800	0.25630	0.28510	0.60973	1.51280	0.06230	0.24245	24.28250	21.36516
B		0.08000	0.25280	0.28510	0.43386	1.55220	0.06230	0.39484	24.91493	22.83904
F	50.65000	0.41000	0.26950	0.27190	0.98219	0.96990	0.06230	0.00898	15.56822	10.86872
E		0.33100	0.25810	0.27190	0.88251	1.41000	0.06230	0.06241	22.63242	18.40989
D		0.25100	0.24900	0.27190	0.76850	1.49030	0.06230	0.13090	23.92135	20.24433
C		0.16800	0.23800	0.27190	0.62872	1.52660	0.06230	0.22795	24.50401	21.49576
B		0.08400	0.23797	0.27190	0.44458	1.55140	0.06230	0.38449	24.90209	22.77493
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.40740	0.06230	0.05281	22.59069	18.28603
D		0.25900	0.24250	0.26500	0.78065	1.50300	0.06230	0.12319	24.12520	20.39004
C		0.17400	0.23460	0.26500	0.63985	1.53730	0.06230	0.21962	24.67576	21.61427
B		0.08700	0.22690	0.26500	0.45244	1.55630	0.06230	0.37699	24.98074	22.81593
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.39270	0.06230	0.03599	22.35474	17.90245
D		0.27100	0.23410	0.25640	0.79853	1.51410	0.06230	0.11202	24.30337	20.48266
C		0.18200	0.22560	0.25640	0.65440	1.54950	0.06230	0.20890	24.87159	21.74050
B		0.09100	0.22040	0.25640	0.46273	1.56290	0.06230	0.36731	25.08668	22.87267
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.28930	0.06230	0.02536	20.69502	16.14698
D		0.29200	0.22200	0.24300	0.82889	1.51170	0.06230	0.09356	24.26485	20.29887
C		0.19700	0.21176	0.24300	0.68083	1.56690	0.06230	0.18989	25.15088	21.89332
B		0.09800	0.20509	0.24300	0.48020	1.58980	0.06230	0.35117	25.51846	23.22087
E	38.63000	0.40900	0.23000	0.23330	0.98100	1.10760	0.06230	0.00959	17.77849	13.08473
D		0.31000	0.21400	0.23330	0.85406	1.50910	0.06230	0.07872	24.22311	20.13672
C		0.20900	0.20200	0.23330	0.70126	1.56990	0.06230	0.17560	25.19904	21.84373
B		0.10500	0.19400	0.23330	0.49705	1.58980	0.06230	0.33596	25.51846	23.14023
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.49450	0.06230	0.06697	23.98876	19.80467
C		0.21800	0.19400	0.22600	0.71620	1.56700	0.06230	0.16537	25.15249	21.72570
B		0.11000	0.18500	0.22600	0.50875	1.58720	0.06230	0.32560	25.47673	23.04253
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.48330	0.06230	0.06166	23.80899	19.58008
C		0.22400	0.19070	0.22260	0.72599	1.56540	0.06230	0.15876	25.12681	21.65318
B		0.11300	0.18110	0.22260	0.51564	1.58850	0.06230	0.31958	25.49759	23.03043
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.41280	0.06230	0.04078	22.67737	18.26763
C		0.24200	0.17900	0.21100	0.75459	1.55910	0.06230	0.13986	25.02568	21.41519
B		0.12200	0.16700	0.21100	0.53578	1.58850	0.06230	0.30227	25.49759	22.93406
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.12490	0.06230	0.01453	18.05618	13.40855
C		0.27100	0.16820	0.19800	0.79853	1.56520	0.06230	0.11202	25.12360	21.30289
B		0.13700	0.15170	0.19800	0.56776	1.58740	0.06230	0.27570	25.47994	22.76337
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.56560	0.06230	0.09526	25.13002	21.17764
B		0.14100	0.14320	0.19100	0.57599	1.58530	0.06230	0.26904	25.44623	22.69029
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.47480	0.06230	0.07238	23.67255	19.53377
B		0.16000	0.13480	0.18360	0.61357	1.58150	0.06230	0.23949	25.38523	22.44948
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.20680	0.06230	0.01957	19.37079	14.76975
B		0.20400	0.11850	0.16700	0.69282	1.55880	0.06230	0.18146	25.02087	21.70594
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.56400	0.06230	0.16537	25.10433	21.67754
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.20060	0.06230	0.07792	19.27127	15.17829

TABLE 3.16 Analysis of Data for S1 - 5 Series.

S2 - 2 SERIES d = 11.02 cm. slope = 0.01730 Q = 20.989 lt/sec.

SECTION	η	τ	h_τ (m.)	h_η (m.)	$(\tau/\tau_0)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\tau/\tau_0)^{0.5}}{1+(\tau/\tau_0)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\tau}{\tau_0}}$
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.25078	0.06050	0.02536	20.67405	16.12600
D		0.29200	0.22200	0.24300	0.82889	1.41390	0.06050	0.09356	23.37025	19.40427
C		0.19700	0.21176	0.24300	0.68083	1.42790	0.06050	0.18989	23.60165	20.34409
B		0.09800	0.20509	0.24300	0.48020	1.47625	0.06050	0.35117	24.40083	22.10324
E	38.63000	0.40900	0.23000	0.23330	0.98100	1.12986	0.06050	0.00959	18.67537	13.98161
D		0.31000	0.21400	0.23330	0.85406	1.47669	0.06050	0.07872	24.40810	20.32171
C		0.20900	0.20200	0.23330	0.70126	1.48319	0.06050	0.17560	24.51554	21.16023
B		0.10500	0.19400	0.23330	0.49705	1.47306	0.06050	0.33596	24.34810	21.96987
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.47175	0.06050	0.06697	24.32645	20.14236
C		0.21800	0.19400	0.22600	0.71620	1.50231	0.06050	0.16537	24.83157	21.40478
B		0.11000	0.18500	0.22600	0.50875	1.47103	0.06050	0.32560	24.31455	21.88035
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.45730	0.06050	0.06166	24.08760	19.85869
C		0.22400	0.19070	0.22260	0.72599	1.50442	0.06050	0.15876	24.86645	21.39282
B		0.11300	0.18110	0.22260	0.51564	1.47016	0.06050	0.31958	24.30017	21.83300
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.31752	0.06050	0.04078	21.77719	17.36745
C		0.24200	0.17900	0.21100	0.75459	1.50414	0.06050	0.13986	24.86182	21.25132
B		0.12200	0.16700	0.21100	0.53578	1.46462	0.06050	0.30227	24.20860	21.64506
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.06722	0.06050	0.01453	17.64000	12.99237
C		0.27100	0.16820	0.19800	0.79853	1.49185	0.06050	0.11202	24.65868	20.83797
B		0.13700	0.15170	0.19800	0.56776	1.45666	0.06050	0.27570	24.07702	21.36046
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.47053	0.06050	0.09526	24.30628	20.35391
B		0.14100	0.14320	0.19100	0.57599	1.45273	0.06050	0.26904	24.01207	21.25613
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.40690	0.06050	0.07238	23.25455	19.11576
B		0.16000	0.13480	0.18360	0.61357	1.44034	0.06050	0.23949	23.80727	20.87152
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.08706	0.06050	0.01957	17.96793	13.36690
B		0.20400	0.11850	0.16700	0.69282	1.42490	0.06050	0.18146	23.55207	20.23714
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.40302	0.06050	0.16537	23.19041	19.76362
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.27444	0.06050	0.07792	21.06512	16.97215

TABLE 3.17 Analysis of Data for S2 - 2 Series.

S2 - 3 SERIES d = 14.98 cm. slope = 0.01730 Q = 38.493 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	55.34000	0.38600	0.27930	0.28510	0.95301	1.46050	0.06713	0.02406	21.75629	17.19642
F	50.65000	0.41000	0.26950	0.27190	0.98219	1.38340	0.06713	0.00898	20.60778	15.90828
E		0.33100	0.25810	0.27190	0.88251	1.64985	0.06713	0.06241	24.57694	20.35441
D		0.25100	0.24900	0.27190	0.76850	1.71320	0.06713	0.13090	25.52063	21.84361
C		0.16800	0.23800	0.27190	0.62872	1.72804	0.06713	0.22795	25.74170	22.73345
B		0.08400	0.23797	0.27190	0.44458	1.74948	0.06713	0.38449	26.06108	23.93392
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.65018	0.06713	0.05281	24.58186	20.27720
D		0.25900	0.24250	0.26500	0.78065	1.71653	0.06713	0.12319	25.57024	21.83508
C		0.17400	0.23460	0.26500	0.63985	1.72234	0.06713	0.21962	25.65679	22.59529
B		0.08700	0.22690	0.26500	0.45244	1.74383	0.06713	0.37699	25.97691	23.81211
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.61758	0.06713	0.03599	24.09623	19.64394
D		0.27100	0.23410	0.25640	0.79853	1.70217	0.06713	0.11202	25.35632	21.53562
C		0.18200	0.22560	0.25640	0.65440	1.71607	0.06713	0.20890	25.56338	22.43230
B		0.09100	0.22040	0.25640	0.46273	1.73748	0.06713	0.36731	25.88232	23.66831
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.50546	0.06713	0.02536	22.42604	17.87799
D		0.29200	0.22200	0.24300	0.82889	1.64250	0.06713	0.09356	24.46745	20.50147
C		0.19700	0.21176	0.24300	0.68083	1.69825	0.06713	0.18989	25.29793	22.04037
B		0.09800	0.20509	0.24300	0.48020	1.72690	0.06713	0.35117	25.72471	23.42712
E	38.63000	0.40900	0.23000	0.23330	0.98100	1.36658	0.06713	0.00959	20.35722	15.66346
D		0.31000	0.21400	0.23330	0.85406	1.63530	0.06713	0.07872	24.36020	20.27380
C		0.20900	0.20200	0.23330	0.70126	1.68725	0.06713	0.17560	25.13407	21.77876
B		0.10500	0.19400	0.23330	0.49705	1.71909	0.06713	0.33596	25.60837	23.23014
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.62445	0.06713	0.06697	24.19857	20.01448
C		0.21800	0.19400	0.22600	0.71620	1.68025	0.06713	0.16537	25.02979	21.60300
B		0.11000	0.18500	0.22600	0.50875	1.71412	0.06713	0.32560	25.53434	23.10014
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.61540	0.06713	0.06166	24.06376	19.83485
C		0.22400	0.19070	0.22260	0.72599	1.67675	0.06713	0.15876	24.97766	21.50403
B		0.11300	0.18110	0.22260	0.51564	1.71198	0.06713	0.31958	25.50246	23.03529
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.52755	0.06713	0.04078	22.75510	18.34536
C		0.24200	0.17900	0.21100	0.75459	1.66876	0.06713	0.13986	24.85863	21.24814
B		0.12200	0.16700	0.21100	0.53578	1.70478	0.06713	0.30227	25.39520	22.83167
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.40094	0.06713	0.01453	20.86906	16.22143
C		0.27100	0.16820	0.19800	0.79853	1.65585	0.06713	0.11202	24.66632	20.84561
B		0.13700	0.15170	0.19800	0.56776	1.69714	0.06713	0.27570	25.28139	22.56483
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.64361	0.06713	0.09526	24.48399	20.53161
B		0.14100	0.14320	0.19100	0.57599	1.69482	0.06713	0.26904	25.24683	22.49090
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.60050	0.06713	0.07238	23.84180	19.70302
B		0.16000	0.13480	0.18360	0.61357	1.69076	0.06713	0.23949	25.18635	22.25060
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.37246	0.06713	0.01957	20.44481	15.84377
B		0.20400	0.11850	0.16700	0.69282	1.66030	0.06713	0.18146	24.73261	21.41768
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.64718	0.06713	0.16537	24.53717	21.11038
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.52634	0.06713	0.07792	22.73708	18.64410

TABLE 3.18 Analysis of Data for S2 - 3 Series.

S2 - 4 SERIES d = 19.45 cm. slope = 0.01730 Q = 61.353 lt/sec.

SECTION	η	ξ	h_ξ (m.)	h_η (m.)	$(\xi/\xi_o)^{0.5}$	U (m./s.)	U_τ (m./s.)	$\frac{1-(\xi/\xi_o)^{0.5}}{1+(\xi/\xi_o)^{0.5}}$	U^*	$U^* - \frac{2}{k}\sqrt{\frac{\xi}{\xi_o}}$
F	59.78000	0.37000	0.28860	0.29640	0.93305	1.76670	0.07226	0.03463	24.44921	19.98484
E		0.29900	0.28020	0.29640	0.83877	1.82330	0.07226	0.08769	25.23249	21.21926
D		0.22600	0.27340	0.29640	0.72922	1.88970	0.07226	0.15659	26.15140	22.66230
C		0.15100	0.26840	0.29640	0.59607	1.90260	0.07226	0.25308	26.32992	23.47793
B		0.07600	0.26540	0.29640	0.42288	1.91420	0.07226	0.40560	26.49045	24.46712
F	55.34000	0.38600	0.27930	0.28510	0.95301	1.59400	0.07226	0.02406	22.05923	17.49936
E		0.31200	0.26970	0.28510	0.85681	1.74960	0.07226	0.07712	24.21257	20.11301
D		0.23600	0.26200	0.28510	0.74518	1.81280	0.07226	0.14601	25.08719	21.52173
C		0.15800	0.25630	0.28510	0.60973	1.86230	0.07226	0.24245	25.77221	22.85487
B		0.08000	0.25280	0.28510	0.43386	1.89480	0.07226	0.39484	26.22198	24.14609
F	50.65000	0.41000	0.26950	0.27190	0.98219	1.43030	0.07226	0.00898	19.79380	15.09431
E		0.33100	0.25810	0.27190	0.88251	1.69680	0.07226	0.06241	23.48187	19.25934
D		0.25100	0.24900	0.27190	0.76850	1.81180	0.07226	0.13090	25.07335	21.39633
C		0.16800	0.23800	0.27190	0.62872	1.83640	0.07226	0.22795	25.41378	22.40553
B		0.08400	0.23797	0.27190	0.44458	1.87600	0.07226	0.38449	25.96180	23.83465
E	48.30000	0.34400	0.25240	0.26500	0.89967	1.69600	0.07226	0.05281	23.47080	19.16614
D		0.25900	0.24250	0.26500	0.78065	1.81470	0.07226	0.12319	25.11348	21.37832
C		0.17400	0.23460	0.26500	0.63985	1.84490	0.07226	0.21962	25.53141	22.46992
B		0.08700	0.22690	0.26500	0.45244	1.87990	0.07226	0.37699	26.01578	23.85097
E	45.60000	0.36800	0.24710	0.25640	0.93053	1.69130	0.07226	0.03599	23.40576	18.95347
D		0.27100	0.23410	0.25640	0.79853	1.83250	0.07226	0.11202	25.35981	21.53910
C		0.18200	0.22560	0.25640	0.65440	1.85960	0.07226	0.20890	25.73485	22.60376
B		0.09100	0.22040	0.25640	0.46273	1.88840	0.07226	0.36731	26.13341	23.91940
E	41.54000	0.38400	0.23600	0.24300	0.95054	1.61830	0.07226	0.02536	22.39552	17.84747
D		0.29200	0.22200	0.24300	0.82889	1.83700	0.07226	0.09356	25.42209	21.45611
C		0.19700	0.21176	0.24300	0.68083	1.87860	0.07226	0.18989	25.99779	22.74023
B		0.09800	0.20509	0.24300	0.48020	1.91060	0.07226	0.35117	26.44063	24.14304
E	38.63000	0.40900	0.23000	0.23330	0.98100	1.34610	0.07226	0.00959	18.62856	13.93480
D		0.31000	0.21400	0.23330	0.85406	1.80460	0.07226	0.07872	24.97371	20.88731
C		0.20900	0.20200	0.23330	0.70126	1.87740	0.07226	0.17560	25.98118	22.62587
B		0.10500	0.19400	0.23330	0.49705	1.91060	0.07226	0.33596	26.44063	24.06240
D	36.40000	0.32500	0.20800	0.22600	0.87447	1.78000	0.07226	0.06697	24.63327	20.44918
C		0.21800	0.19400	0.22600	0.71620	1.86920	0.07226	0.16537	25.86770	22.44091
B		0.11000	0.18500	0.22600	0.50875	1.91240	0.07226	0.32560	26.46554	24.03134
D	35.52000	0.33200	0.20570	0.22260	0.88384	1.76680	0.07226	0.06166	24.45060	20.22169
C		0.22400	0.19070	0.22260	0.72599	1.87270	0.07226	0.15876	25.91614	22.44251
B		0.11300	0.18110	0.22260	0.51564	1.91280	0.07226	0.31958	26.47108	24.00391
D	32.16000	0.36100	0.19800	0.21100	0.92164	1.67850	0.07226	0.04078	23.22862	18.81888
C		0.24200	0.17900	0.21100	0.75459	1.84600	0.07226	0.13986	25.54664	21.93614
B		0.12200	0.16700	0.21100	0.53578	1.91150	0.07226	0.30227	26.45309	23.88955
D	28.45000	0.40100	0.19270	0.19800	0.97135	1.31520	0.07226	0.01453	18.20094	13.55331
C		0.27100	0.16820	0.19800	0.79853	1.81340	0.07226	0.11202	25.09549	21.27478
B		0.13700	0.15170	0.19800	0.56776	1.90460	0.07226	0.27570	26.35760	23.64104
C	26.50000	0.29000	0.16350	0.19100	0.82605	1.78740	0.07226	0.09526	24.73568	20.78330
B		0.14100	0.14320	0.19100	0.57599	1.89320	0.07226	0.26904	26.19983	23.44390
C	24.22000	0.31800	0.16000	0.18360	0.86501	1.72980	0.07226	0.07238	23.93856	19.79977
B		0.16000	0.13480	0.18360	0.61357	1.87320	0.07226	0.23949	25.92306	22.98730
C	19.16000	0.39300	0.15900	0.16700	0.96162	1.37340	0.07226	0.01957	19.00637	14.40533
B		0.20400	0.11850	0.16700	0.69282	1.81960	0.07226	0.18146	25.18129	21.86636
B	17.30000	0.21800	0.11300	0.16200	0.71620	1.79160	0.07226	0.16537	24.79380	21.36701
B	11.31000	0.31100	0.11380	0.14680	0.85543	1.65050	0.07226	0.07792	22.84113	18.74815

TABLE 3.19 Analysis of Data for S2 - 4 Series.

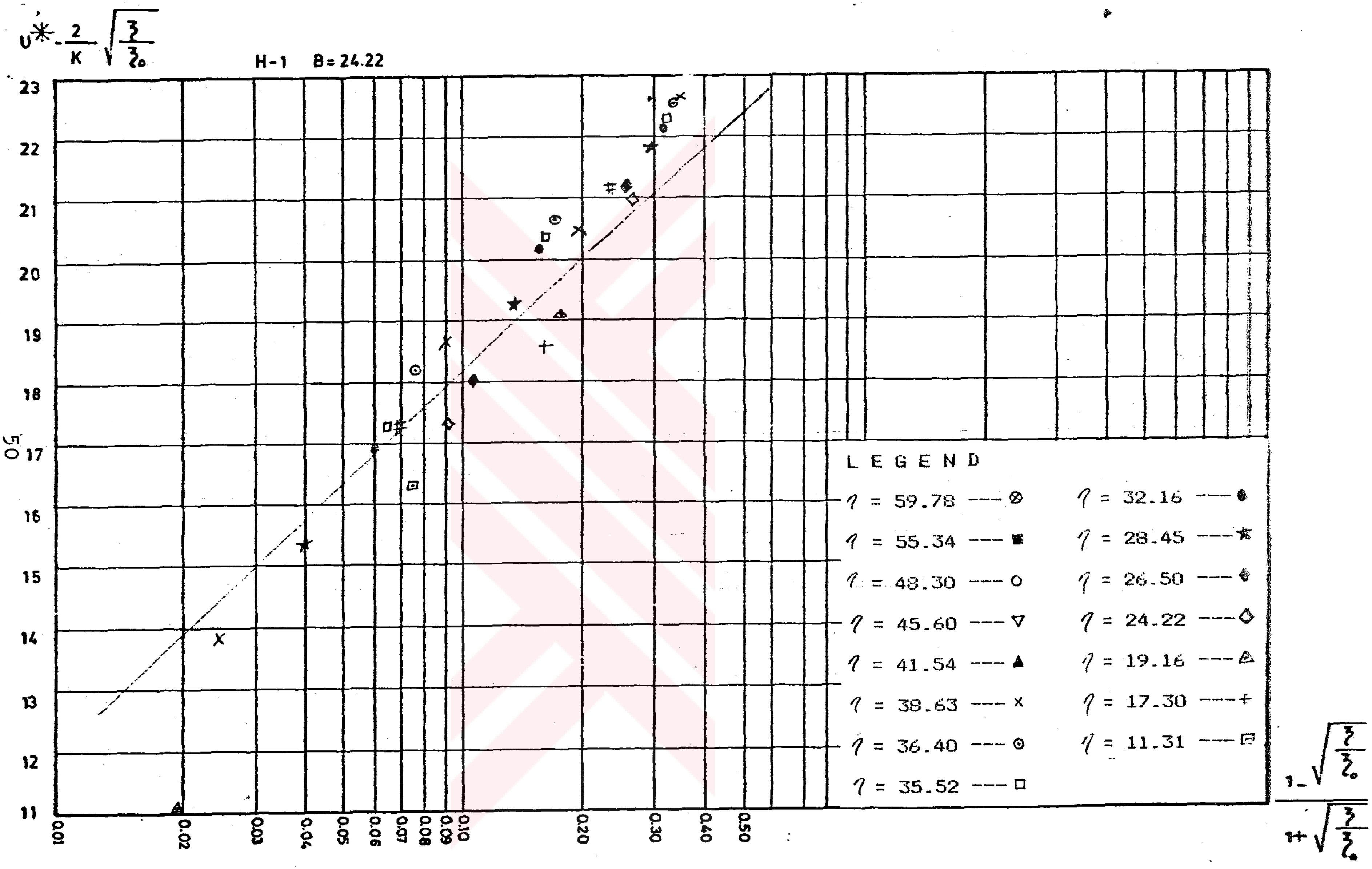


FIG. 3.1

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_o=0.0, d=10.9 cm. AND Q=7.80 lt/sec.

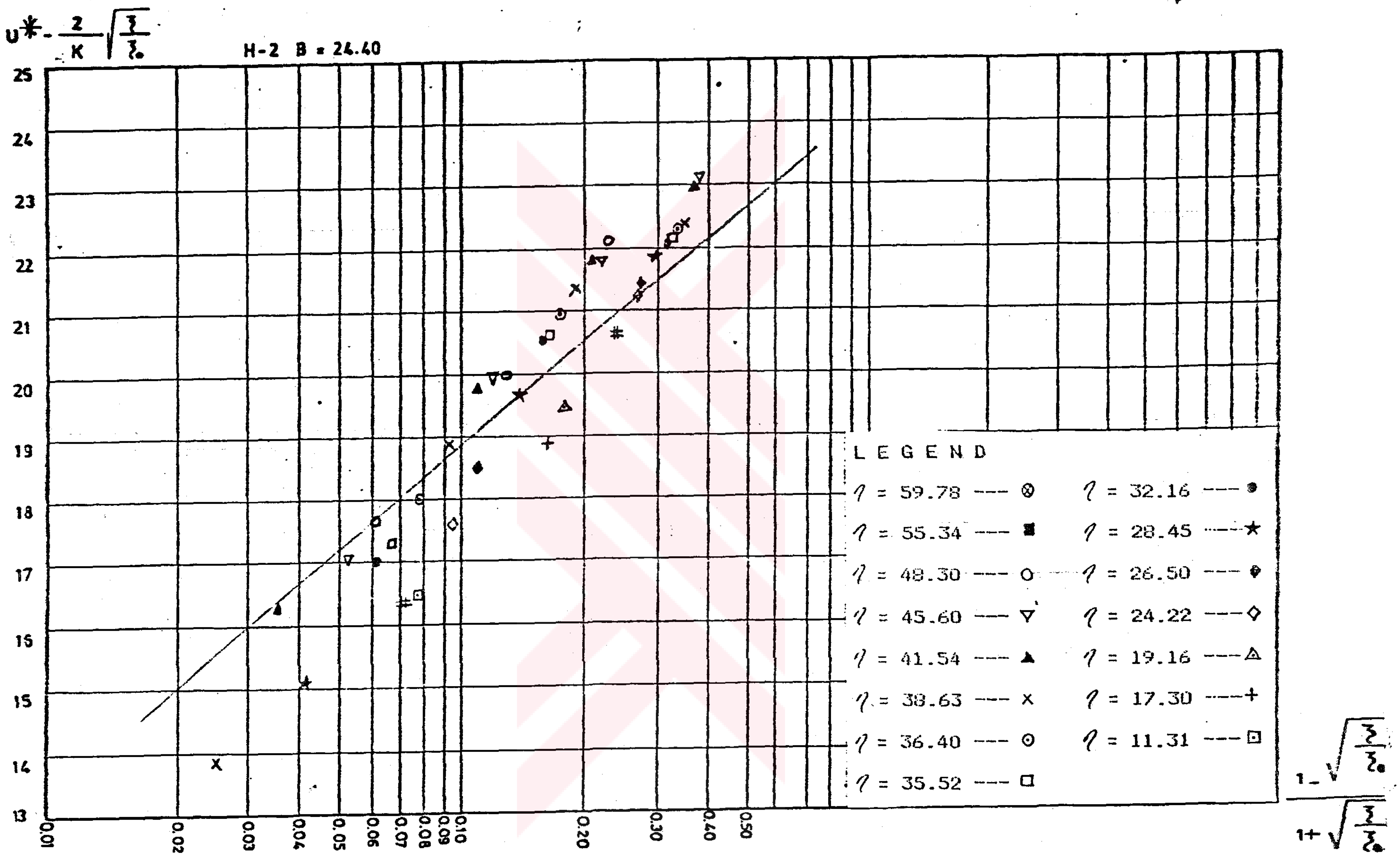


FIG. 3.2 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR $S_o = 0.0$, d=14.7cm. AND Q=14.766 lt/sec.

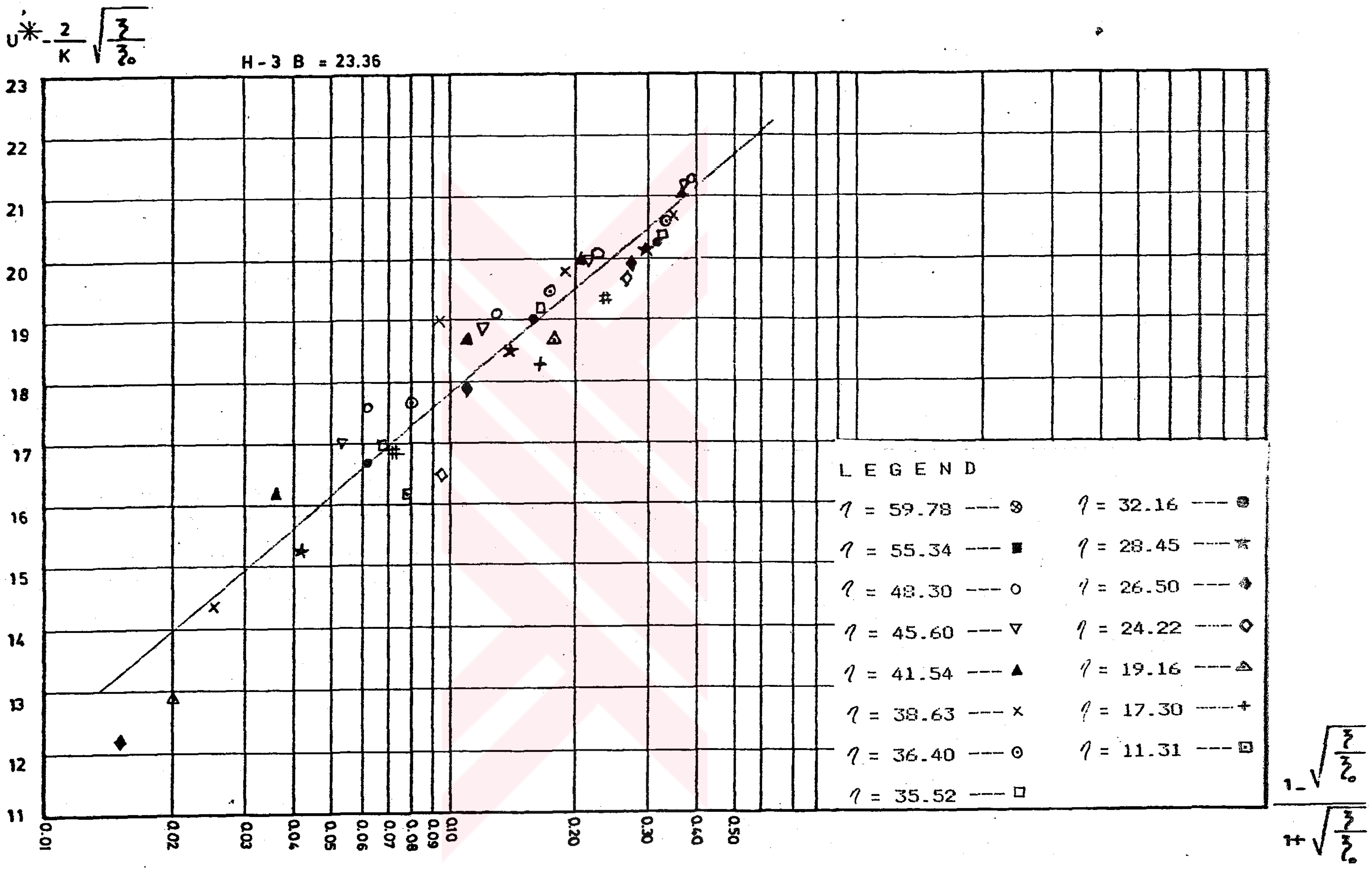


FIG. 3.3

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL
FOR S_o=0.0, d=20.25cm. AND Q=30.209 lt/sec.

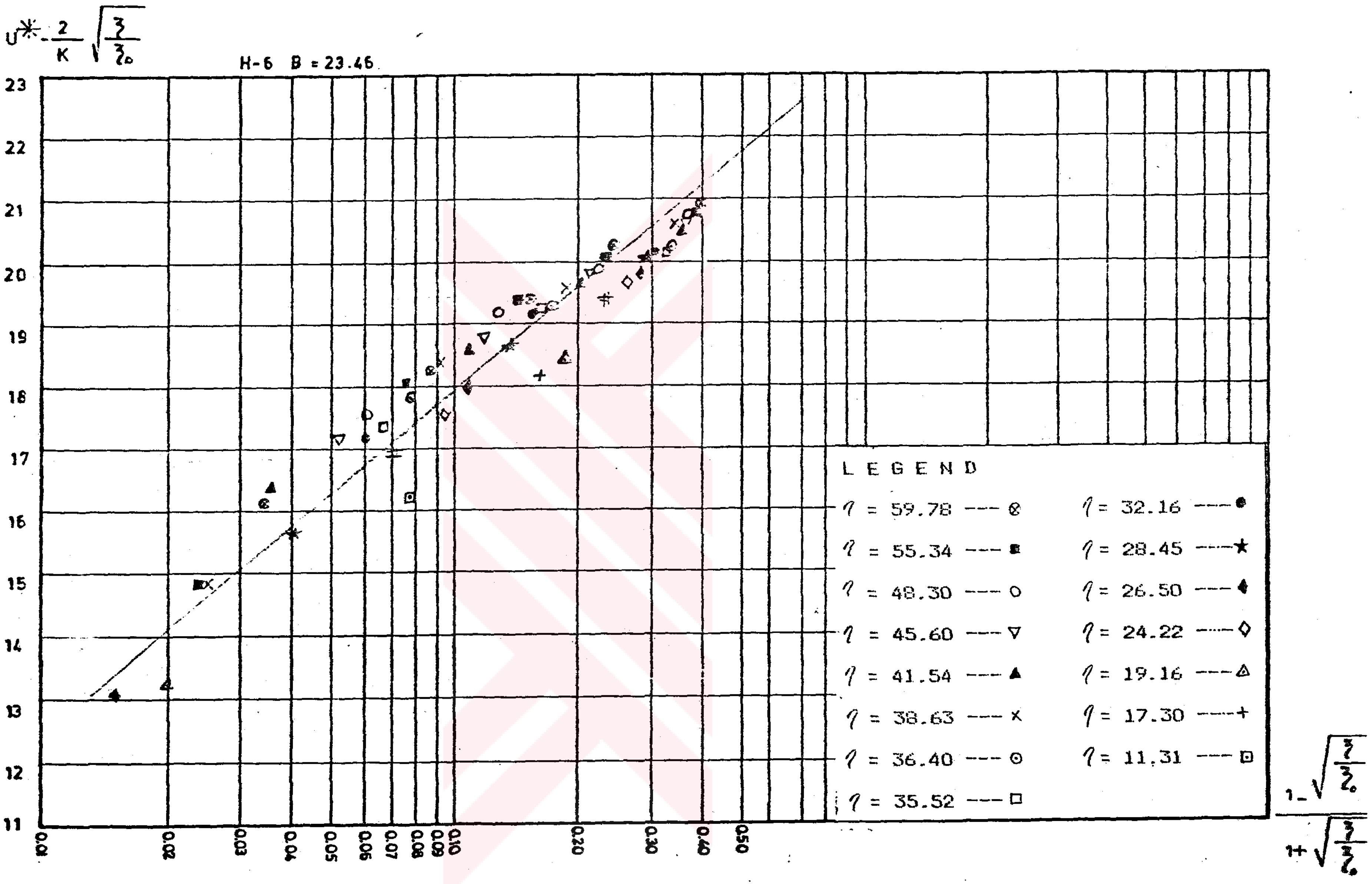


FIG. 3.4

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_o=0.0, d=25.19cm. AND Q=45.096. lt/sec.

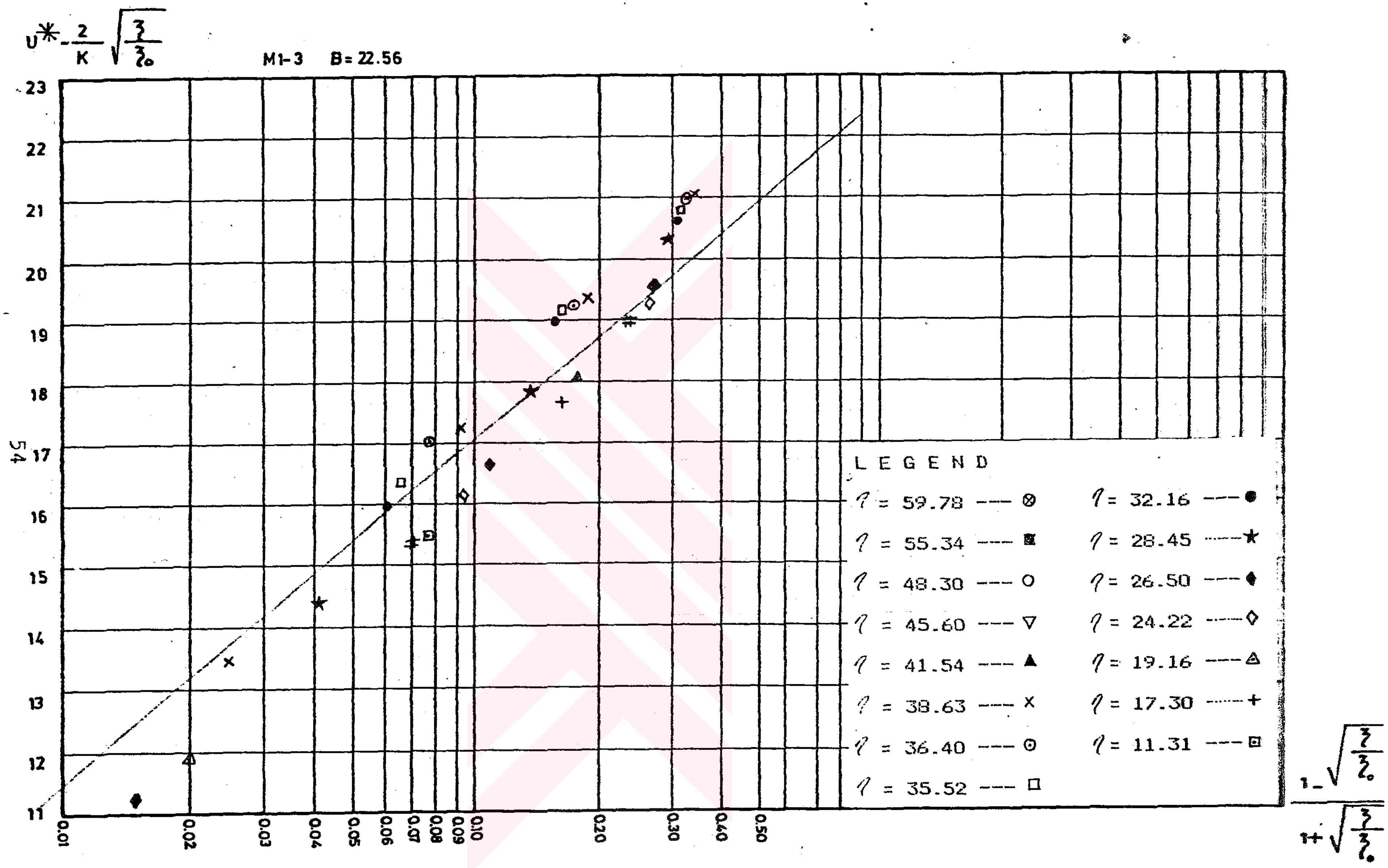


FIG. 3.5

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_0=0.00295, d=10.3 cm. AND Q=9.808 lt/sec.

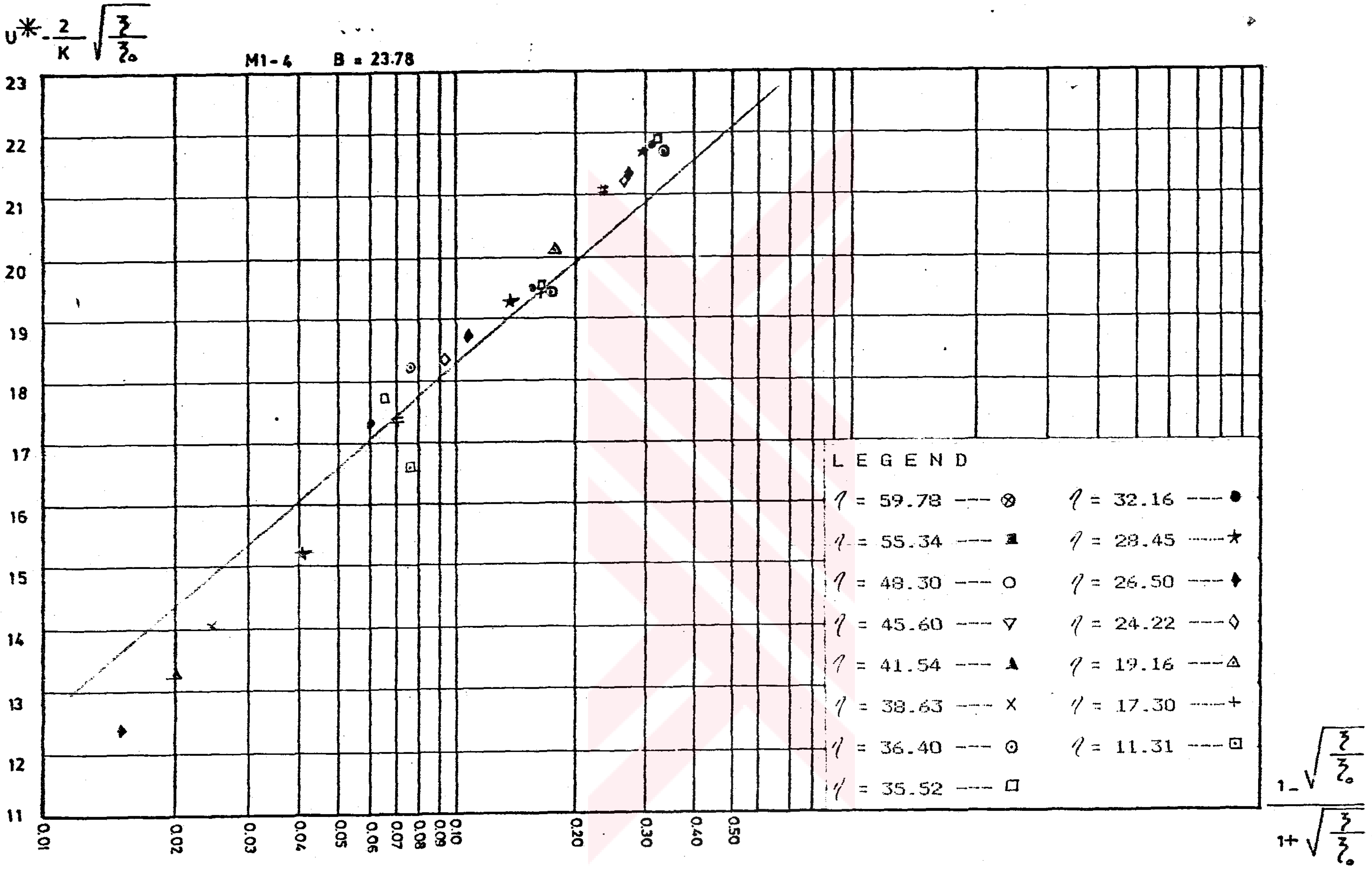


FIG. 3.6

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_o=0.00295, d=10.07cm. AND Q=9.557 lt/sec

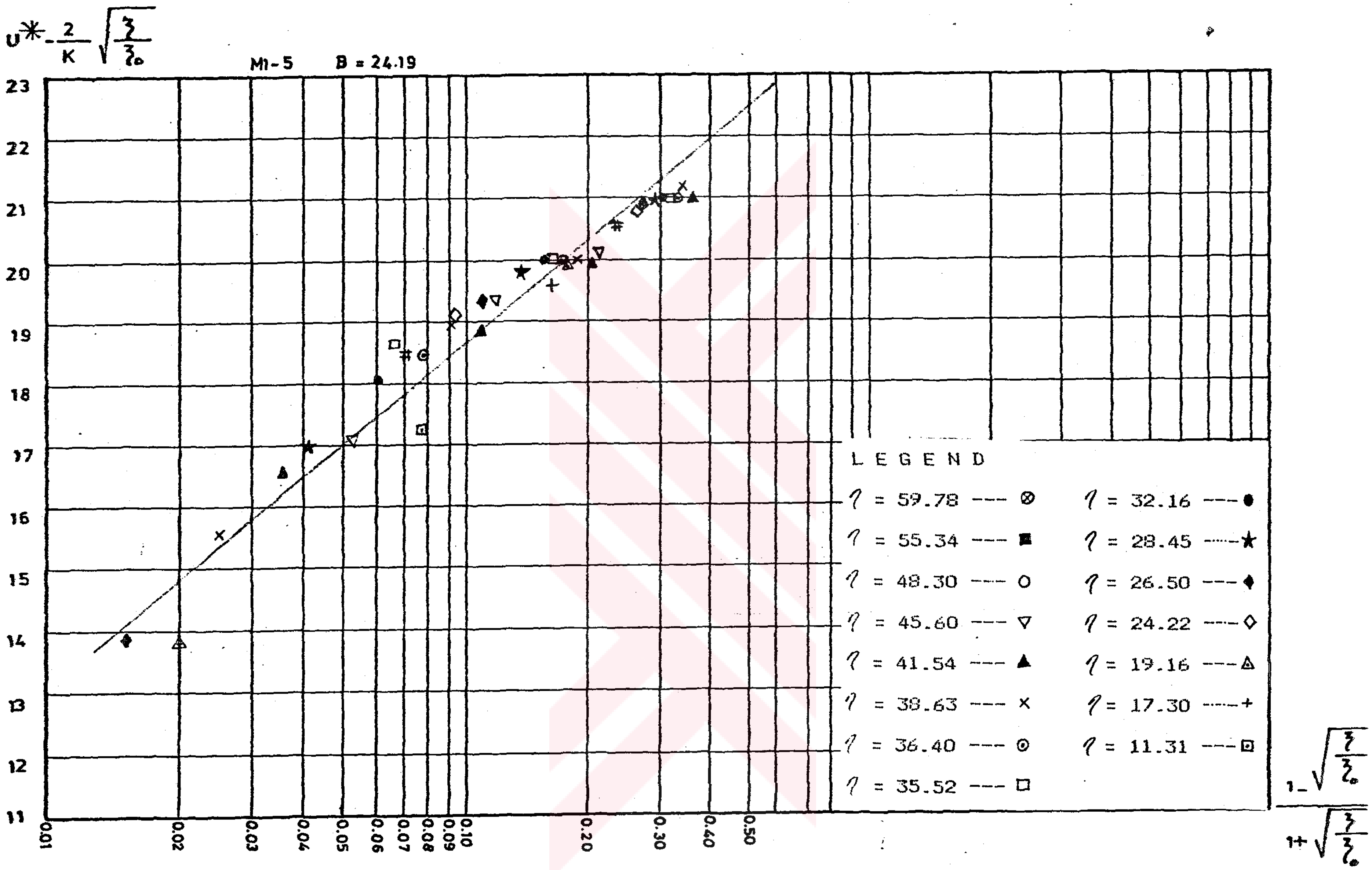


FIG. 3.7

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_0=0.00295, d=13.82 cm. AND Q=19.295 lt/sec.

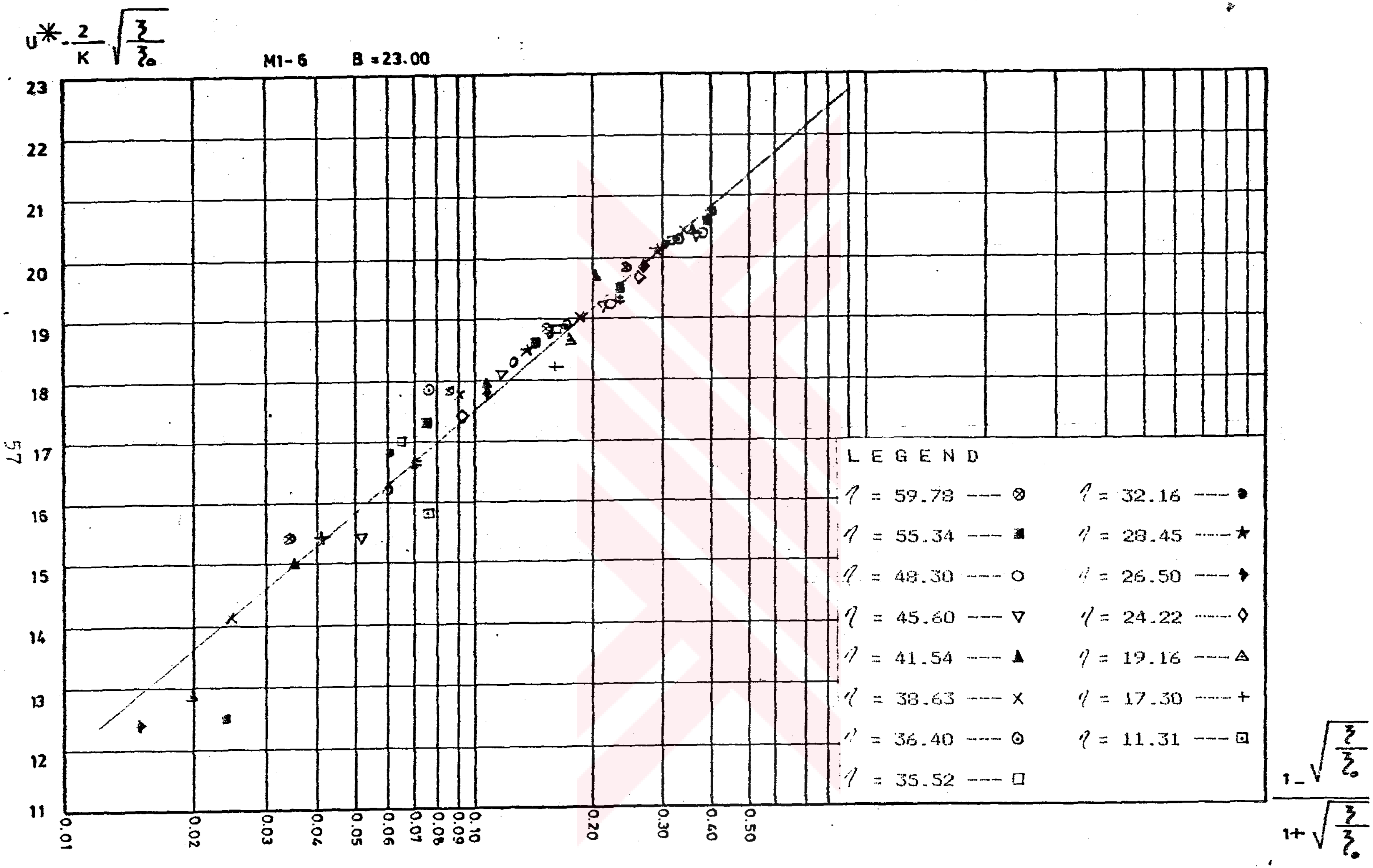


FIG. 3.8

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_0=0.00295, d=19.5 cm, AND Q=31.575 lt/sec.

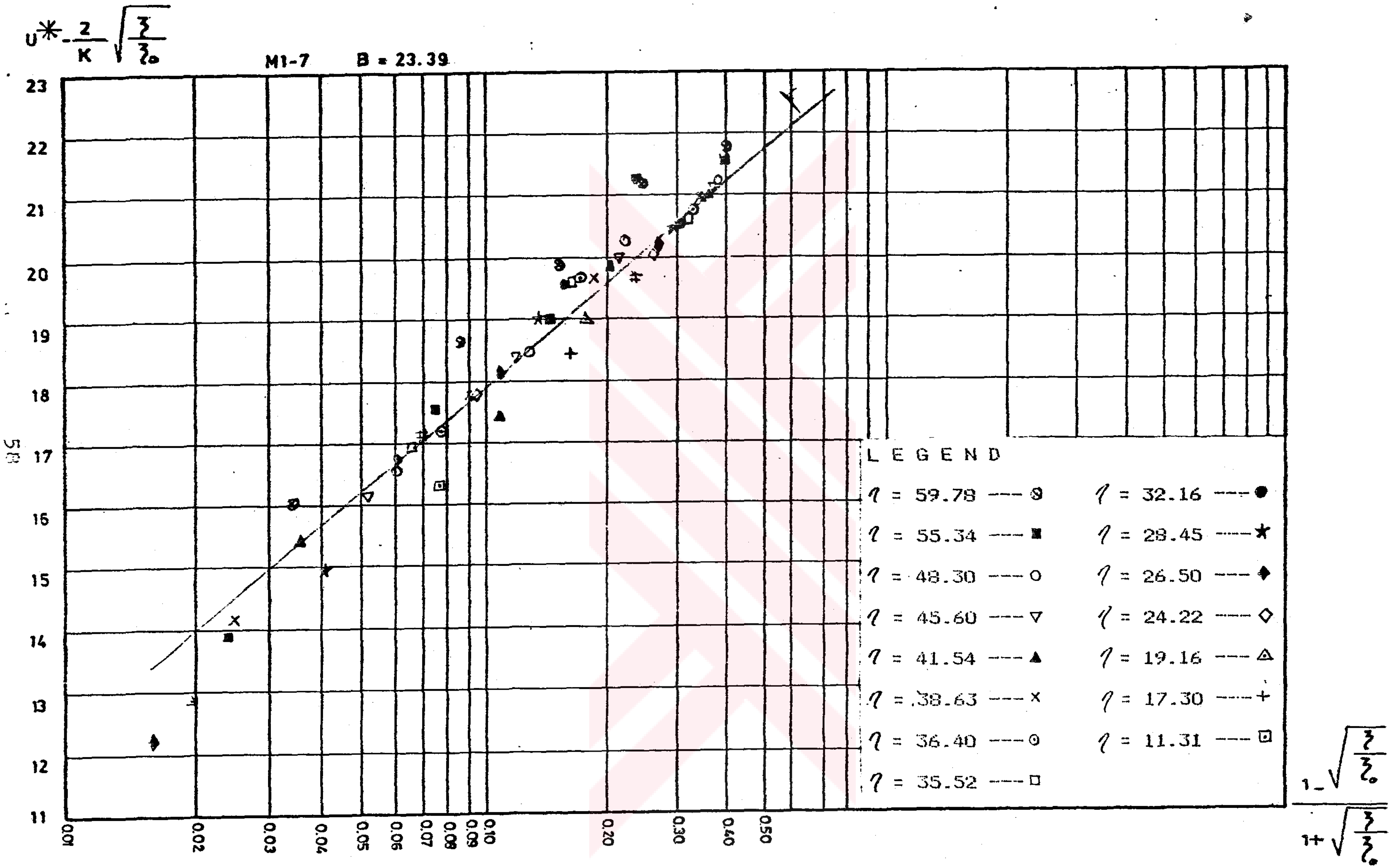


FIG. 3.9

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR S_0=0.00295, d=25.25 cm. AND Q=52.906 lt/sec.

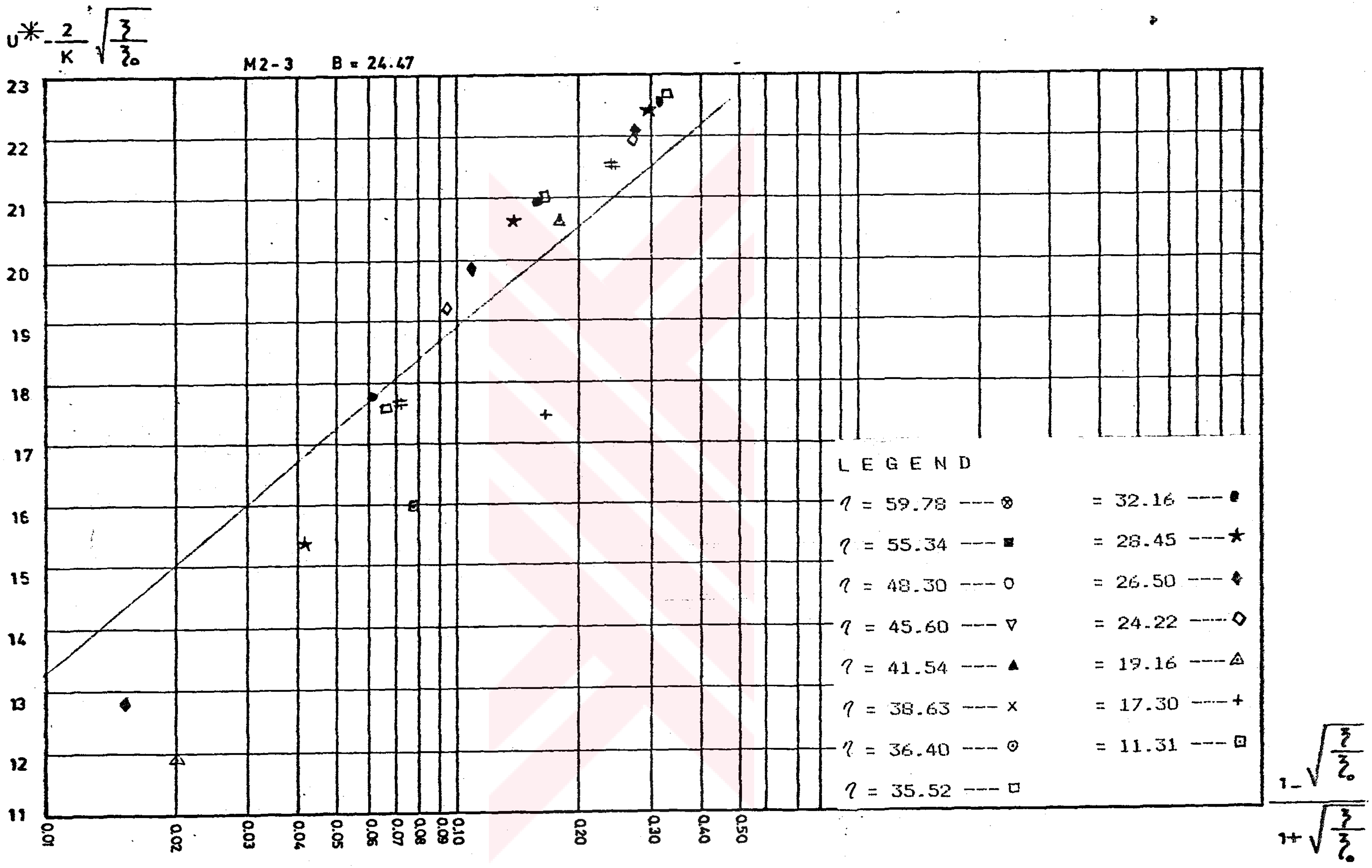


FIG. 3.10

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL
FOR S_o=0.0045 , d=10.0 cm. AND Q= 11.167 lt/sec.

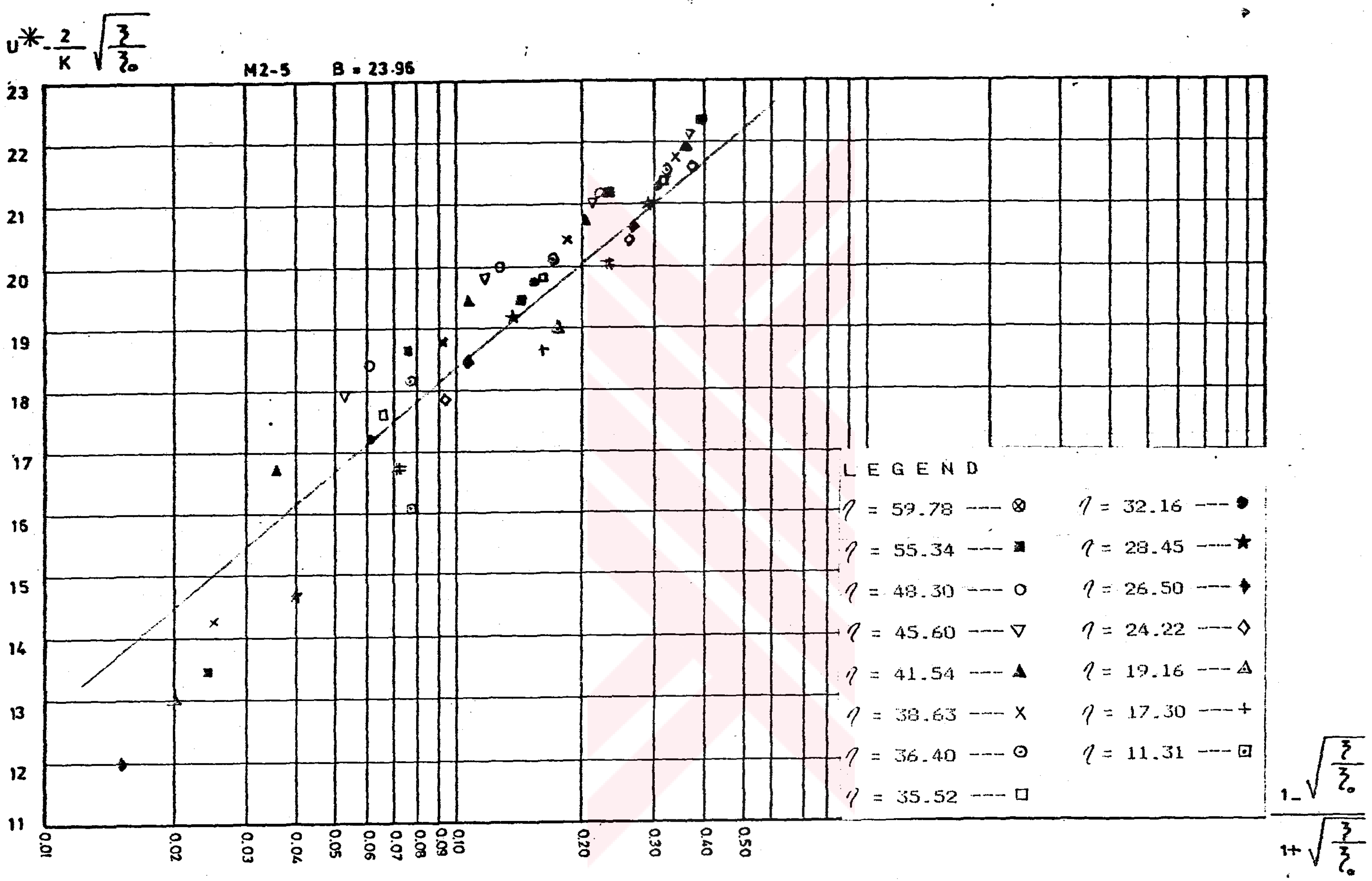


FIG. 3.11

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL FOR $S_o = 0.0045$, d = 15.44 cm. AND Q = 25.753 lt/sec.

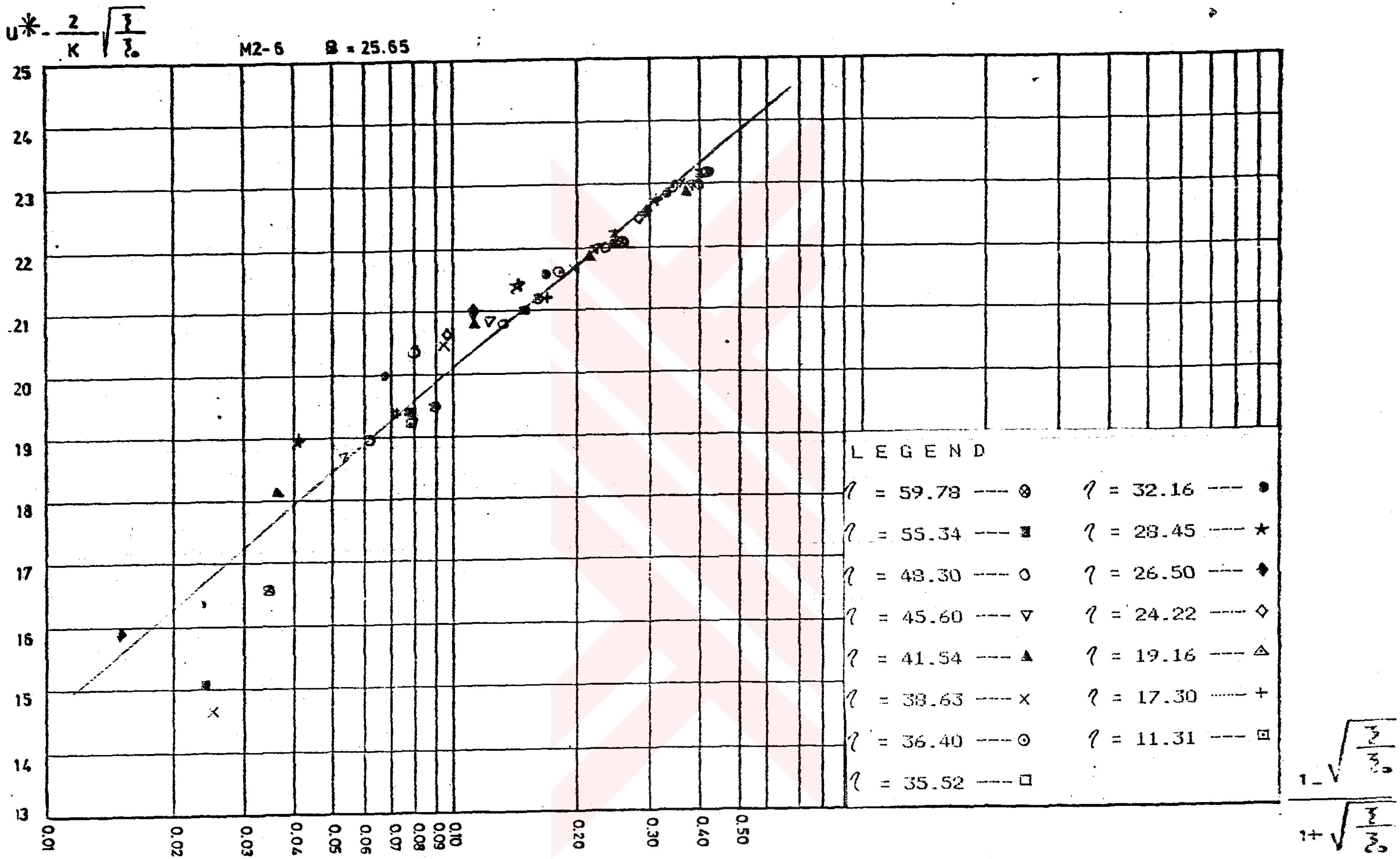


FIG. 3.12 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR $S_o = 0.0045$, d = 20.44 cm. AND Q = 41.193 lt/ sec.

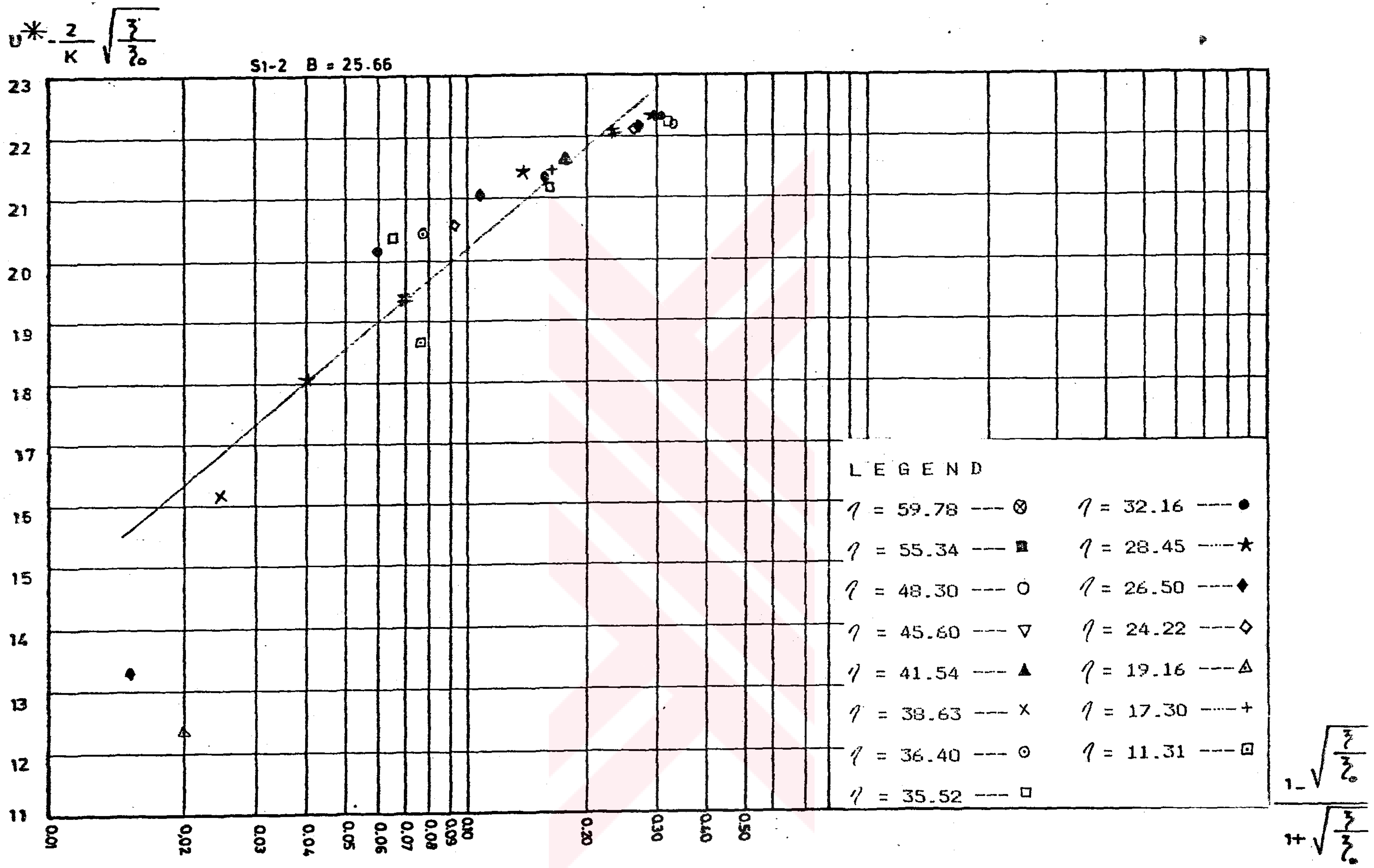


FIG. 3.13

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL
FOR S_o=0.00923, d=10.3 cm. AND Q=15.808 lt/sec.

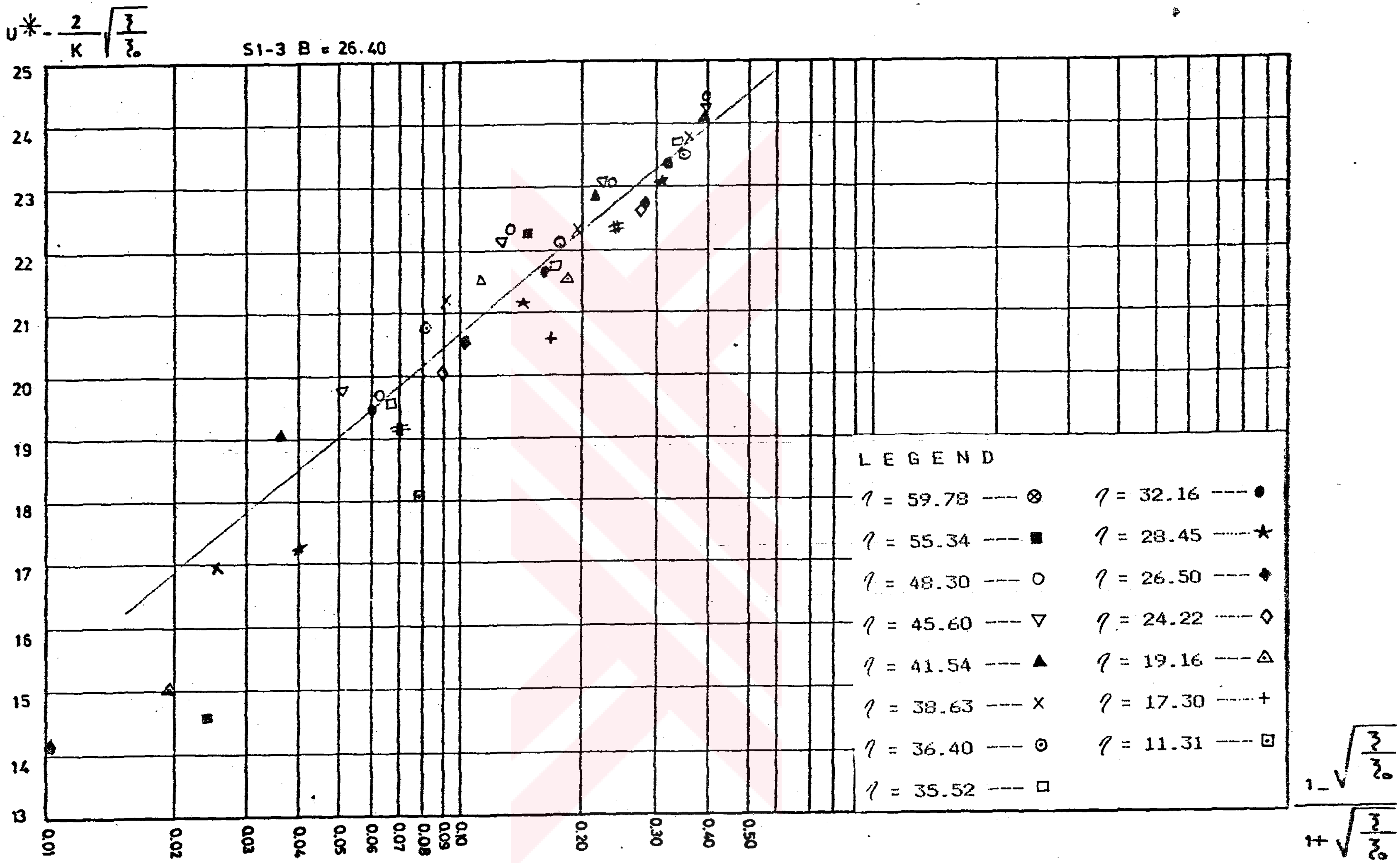


FIG. 3.14 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR S_o=0.00923 , d = 15.36 cm. AND Q=36.230 lt/sec.

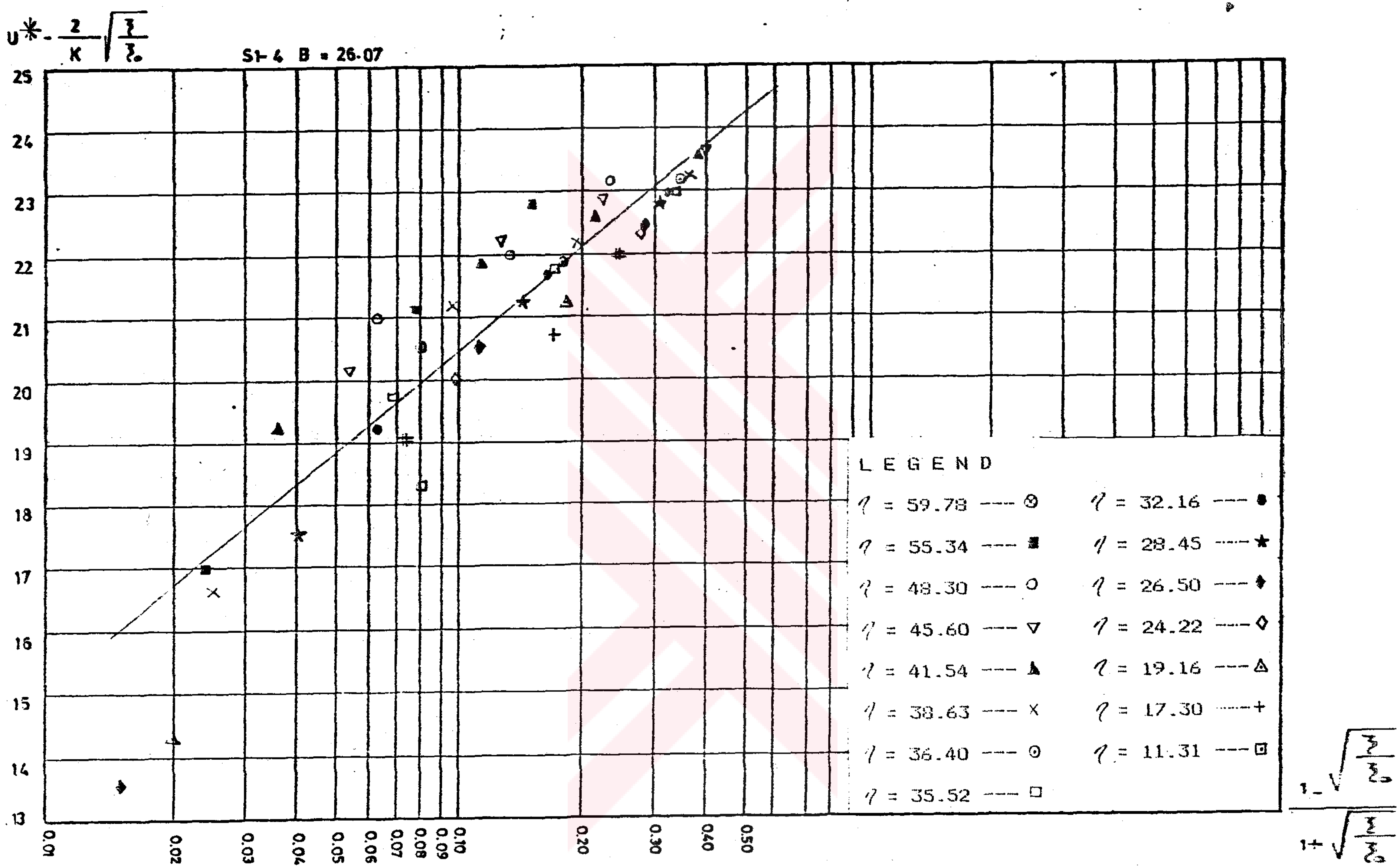


FIG. 3.15 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR S_o=0.00923, d=16.55 cm. AND Q=36.282 lt/sec.

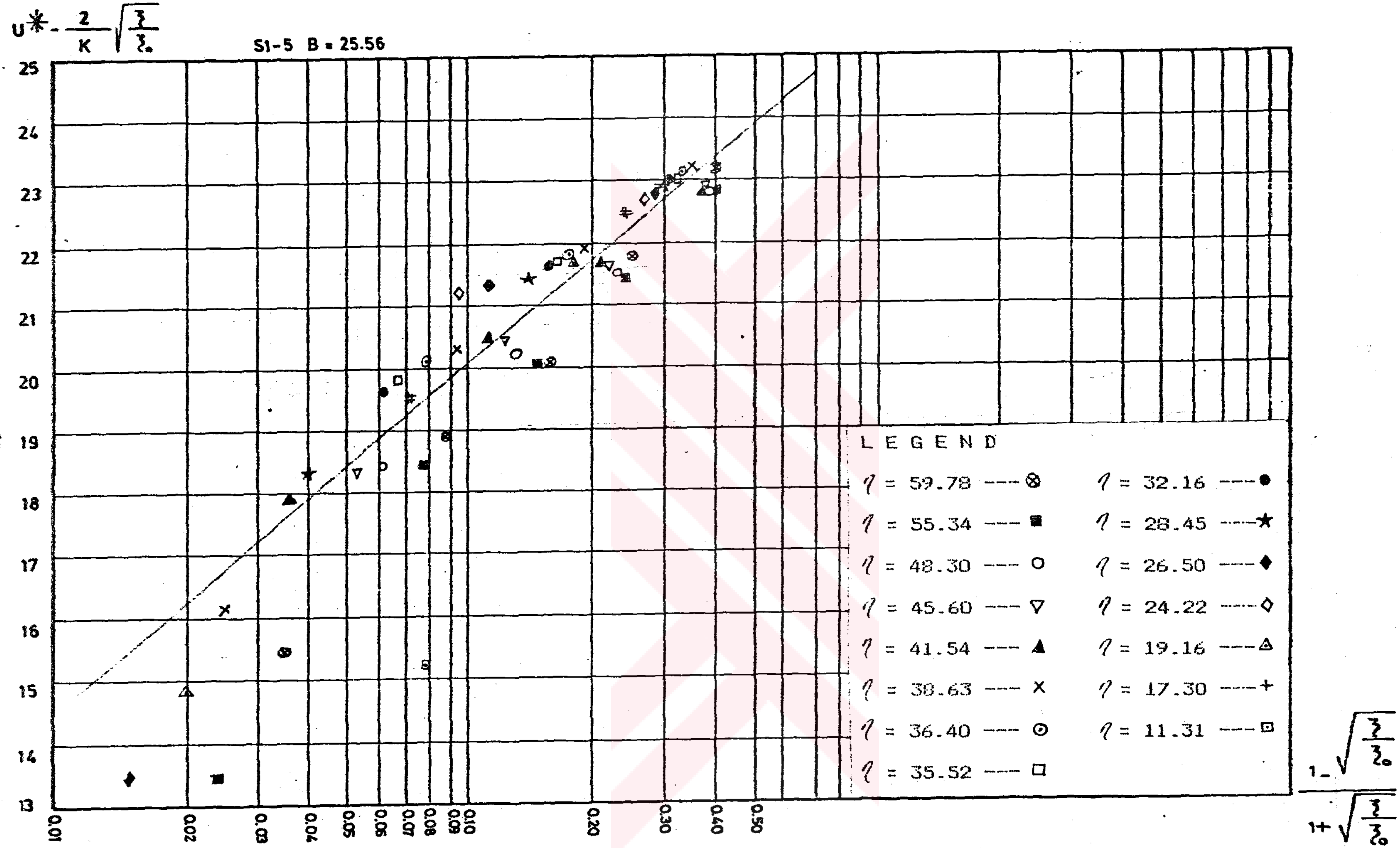


FIG. 3.16 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR S_o=0.00923, d=20.22 cm. AND Q=53.819 lt/sec.

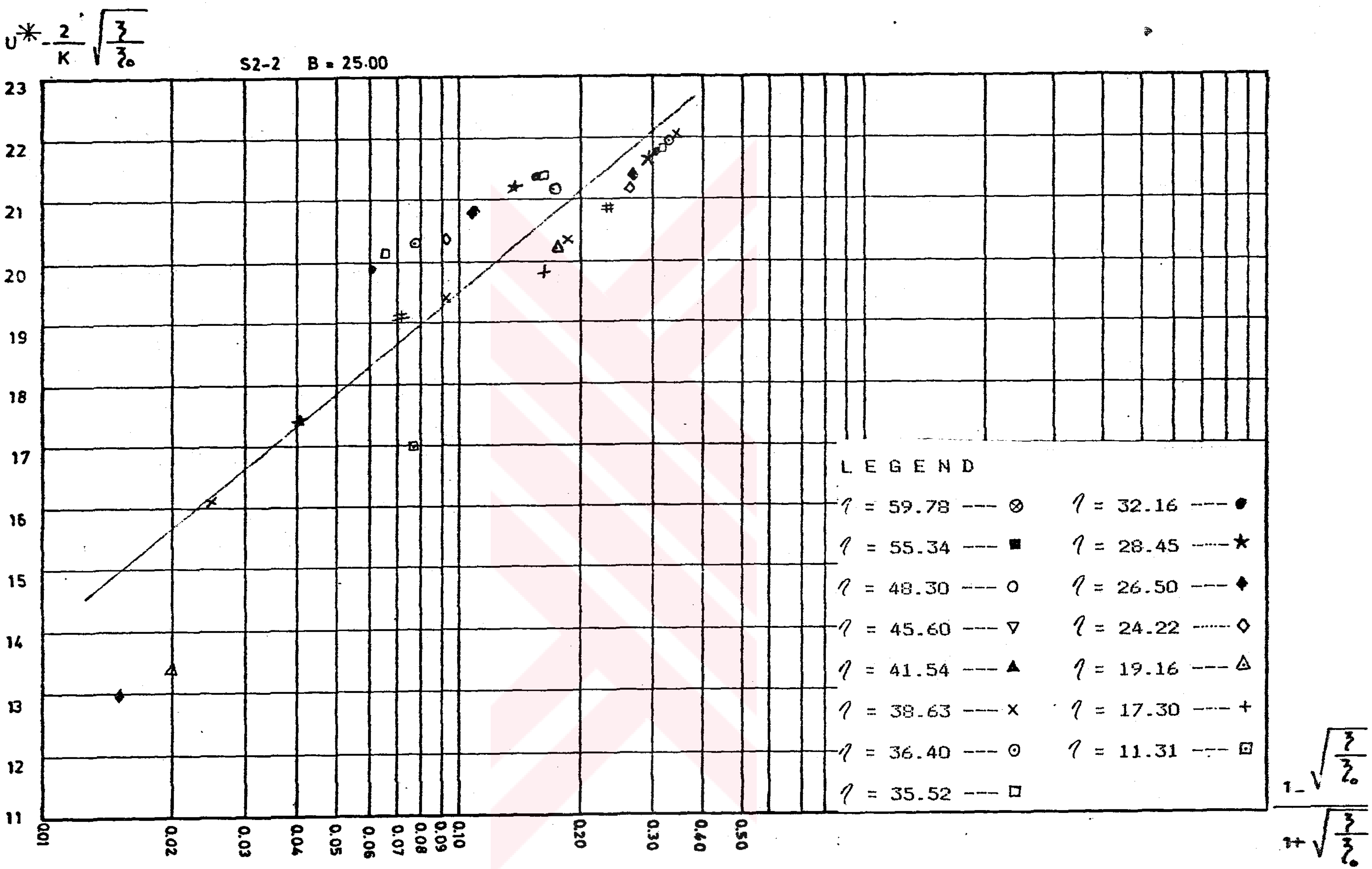


FIG. 3.17

DISTRIBUTION OF THE VELOCITY IN A SEMI-ELLIPTICAL CHANNEL
FOR S_o=0.0173, d=11.02 cm. AND Q=20.989 lt/sec.

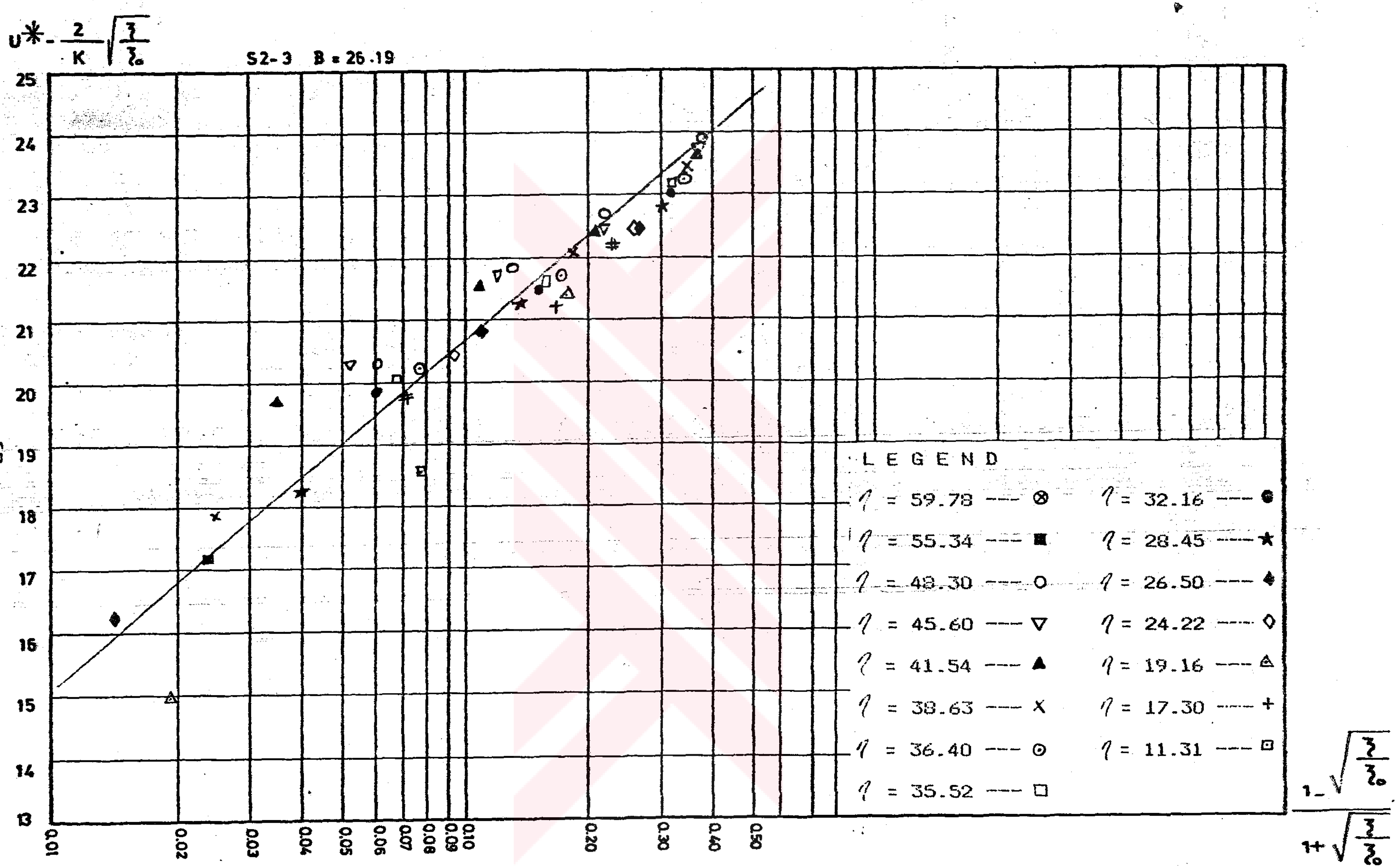


FIG. 3.18 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR S=0.0173, d=14.98 cm. AND Q=38.493 lt/sec.

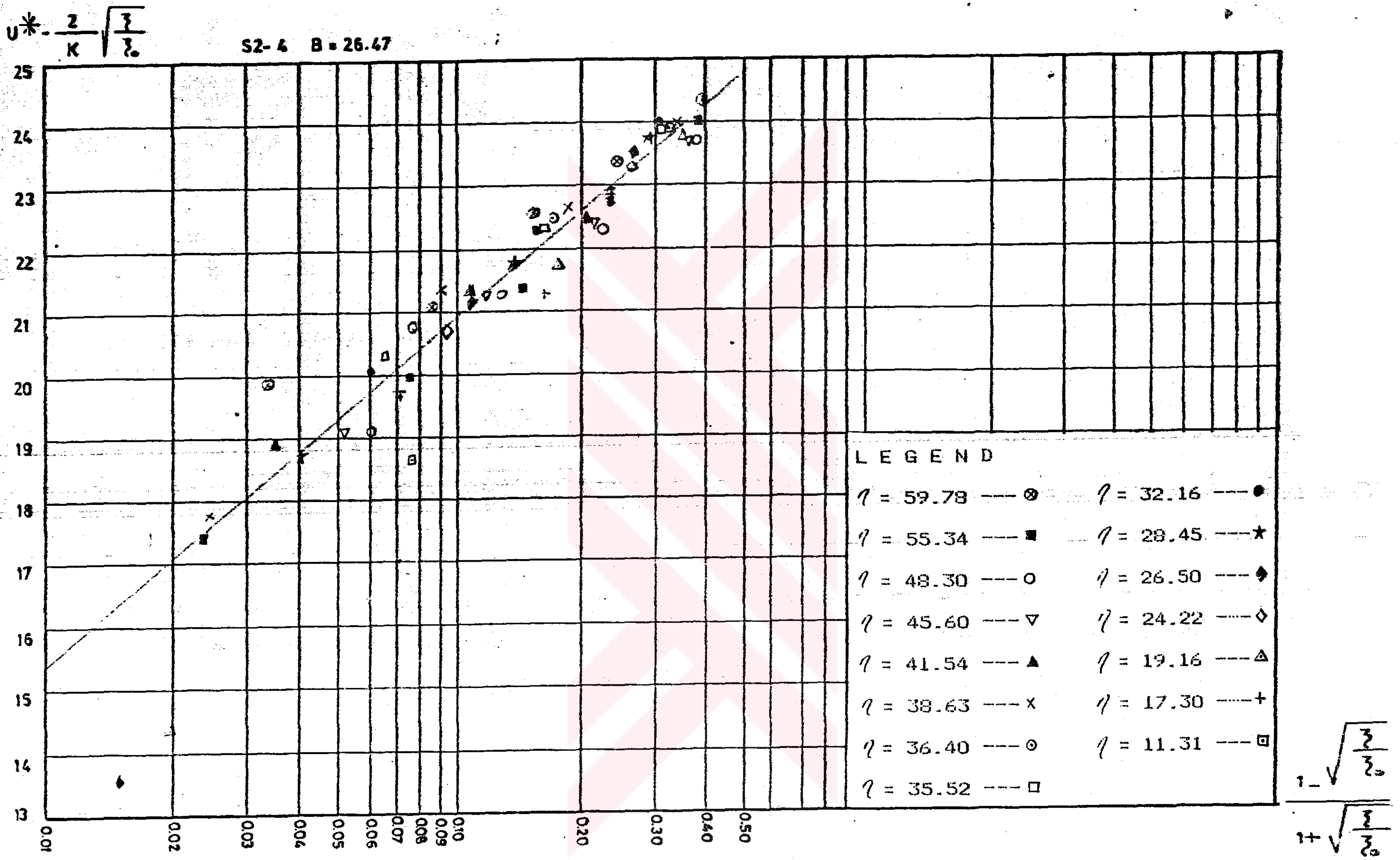


FIG. 3.19 DISTRIBUTION OF THE VELOCITY IN A-SEMI ELLIPTICAL CHANNEL FOR S_0=0.0173, d=19.45 cm. AND Q=61.353 lt/sec.

In these figures , the best-fitting straight line with a slope of 1/0.418 have been drawn . As can be seen from Figures (3.1) - (3.19) , the measured velocity distributions confirm the value of k equals to 0.418 . Also from these figures , the values of B for each set have been determined , and these values are given in Table (3.20).It can be seen from Table (3.20) that , the value of B is changing between 22.56 to 26.47 .

As stated before , the value of B is not universal but may take different values for different flows. For two dimensional flows , for which the classical law of the wall holds true , the value of B is 5.45 .

A survey of literature has showed that , even for the classical law of the wall , the value of B may vary and it might be larger than its expected value of 5.45 as discussed by Patel,V.C. & Head,M.R. (16) , Afzal,N. & Yajnik,K. (17) and Clark,J.A. (18) .

Patel,V.C. & Head,M.R. (16) , in their study , measured the skin friction and determine the velocity distribution for turbulent flows in two pipes having different diameters and also in a rectangular open channel flow .

They showed that , in pipe flows , the flow becomes fully turbulent above a Reynolds number of 3000 , and for the fully turbulent flows , the velocity distribution follows the classical law of the wall . In their study , although the value of k is consistent with the universal value of 0.418 , the value of B is appreciably larger than the expected value of 5.45 . Patel,V.C. & Head,M.R. (16) also showed that the velocity distribution in a rectangular channel flow follows the law of the wall with the values of $k = 0.418$ and $B = 5.45$.

As stated above , the channel used by Patel,V.C. & Head,M.R. (16) was rectangular in cross-section and the measurements were taken at the center , hence the flow may be considered as the same as the flow over a flat plate . It is well-known that the classical law of the wall holds true for a turbulent flow over a flat plate .

Afzal,N. & Yajnik,K. (17) also made a research about the skin friction in turbulent flows at moderately large Reynolds numbers and as Reynolds number approaches infinity the additive constant B approaches to value of 5.45 .

Clark,J.A. (18) also noted an increase in the value of B with decreasing Reynolds number in his study of incompressible turbulent boundary layers in channel flow .

In the studies mentioned above , the curvature effects are not taken into consideration , and hence the values of B in these studies are for the classical law of the wall .

On the other hand , if the flow in a semi-elliptical channel is concerned , there is an effect of curvature of the channel geometry on the velocity distribution .

Consequently the value of B may be different than the classical value of 5.45 . As also indicated by Patel,V.C. & Head,M.R.(16) , in pipe flow , in which there is the effect of curvature , the values of B are larger than 5.45 , and the value of B depends on the Reynolds number .

In this study , to see the variation of B with the Reynolds number , for each set of data , the Reynolds numbers based on hydraulic radius , have been plotted in Figure (3.20). As can be seen from this figure , the result is not conclusive .

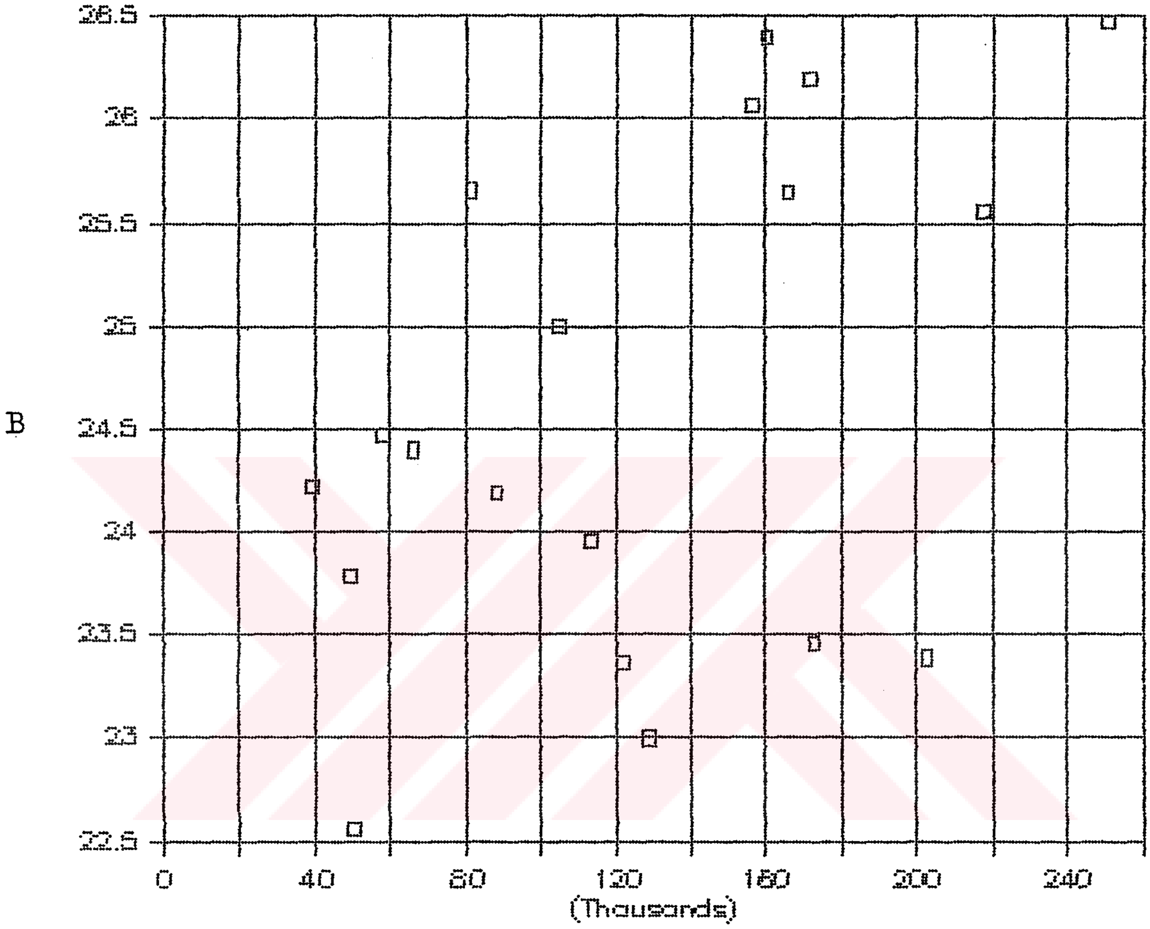
On the other hand , for open channel flows the relative slope, S_o/S_{crit} ,where S_o is the channel bottom slope and S_{crit} is the critical slope ,may become an important parameter as discussed by Balta , A. (19) , Rajaratnam,N.N. & Muralidhar,D. (20) and Delleur,J.W. , Doodge,J.C.I. & Gent,K.N. (21) . Therefore just to see how B values vary with the relative slope , the critical slopes have been calculated for each set of data and the relative slopes have been tabulated in Table (3.20) . The values of B versus relative slopes have been plotted in Figure (3.21). As can be seen from this figure the result is not conclusive because of inadequate data.

It can be seen from Table (3.20) that the B values are changing between 22.56 to 26.47 and have an average of 24.62 .

On the other hand, the average values are , 23.86 for

SERIES	Q (cm3/sec)	A (cm2)	R (cm)	Reynolds Number ($R u / \nu$)	A_{crit} (cm2)	R_{crit} (cm)	S / S_{crit}	B
H-1	7807	149.470	7.549	39298	18.666	1.783	0.000000	24.22
H-2	14766	229.443	10.335	66290	30.044	2.465	0.000000	24.40
H-3	30209	359.930	14.608	122196	51.19	3.552	0.000000	23.36
H-6	45096	485.230	18.677	173000	68.938	4.366	0.000000	23.46
M1-3	9808	137.643	7.111	50502	52.188	3.600	0.003808	22.56
M1-4	9557	133.211	6.945	49659	51.205	3.553	0.003794	23.78
M1-5	19295	210.120	9.678	88575	73.241	4.554	0.002652	24.19
M1-6	31575	341.560	14.016	129136	124.079	6.602	0.004663	23.00
M1-7	52906	486.790	18.730	202884	181.312	8.682	0.005109	23.39
M2-3	11167	131.871	6.897	58210	57.531	3.851	0.005958	24.47
M2-5	25753	246.020	10.886	113573	106.765	5.933	0.006865	23.96
M2-6	41193	364.620	14.762	166217	150.881	7.597	0.007451	25.65
S1-2	15808	137.640	7.111	81397	74.369	4.602	0.012923	25.66
S1-3	36230	244.220	10.825	160053	137.295	7.098	0.014943	26.40
S1-4	36282	271.410	11.729	156269	137.450	7.104	0.014951	26.07
S1-5	53819	359.200	14.587	217828	183.550	8.760	0.016022	25.56
S2-2	20989	151.760	7.628	105146	91.764	5.332	0.025457	25.00
S2-3	38493	235.680	10.542	171605	143.543	7.329	0.028304	26.19
S2-4	61353	340.340	13.976	251104	202.403	9.413	0.030926	26.47

TABLE - 3.20 Table for Reynolds Numbers , S / S_{crit} and B values .



Reynolds Number

Figure 3.20 Variation Of B Values With Reynolds Number

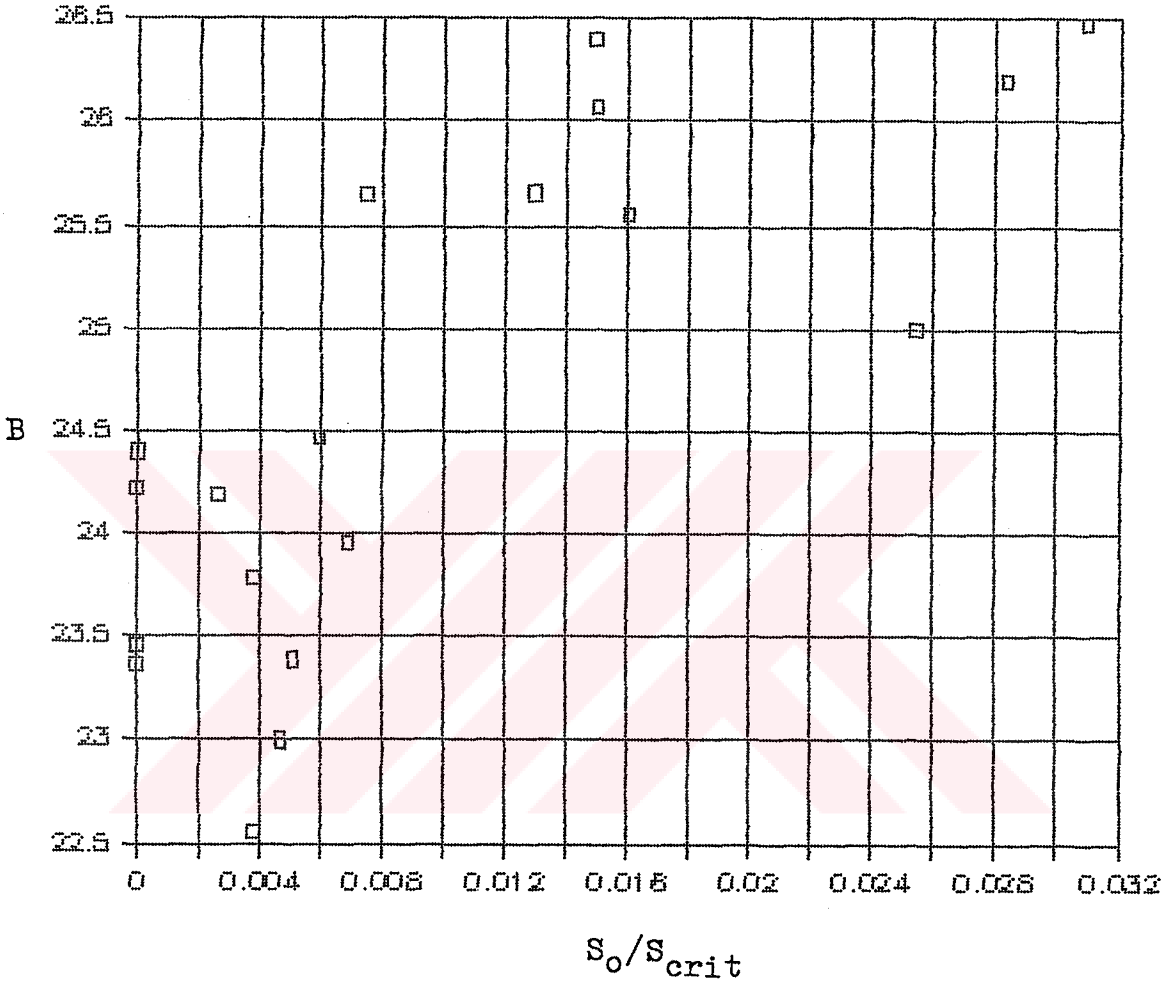


Figure 3.2I Variation Of B Values With Relative Slope

H - Series , 23.38 for M1 - Series , 24.69 for M2 - Series, 25.92 for S1 - Series and 25.89 for S2 - Series .

Since the variation of B is small , an average of B equals to 24.6 may be taken for the law of the wall in a semi-elliptical channel flow.

CONCLUSION

1. The law of the wall in a semi-elliptical open channel flow has been derived . The velocity distributions in the viscous sublayer and the fully turbulent region are given by Equations (2.31) and (2.44) , respectively .

2. The value of von Karman's constant k , in this derived form of the law of the wall confirms the value of 0.418 .

3. The value of B , for the law of the wall for a flow in a semi-elliptical channel given by Equation (2.44) may be considered as 24.6 .

REFERENCES

(1) BAKHMETEFF , B.A.
" The Mechanics of Turbulent Flow "
Princeton University Press , Princeton , 1936 .

(2) CHOW , V.T.
" Open Channel Hydraulics "
McGraw Hill International Book Company , 1982 .

(3) DAILY , J.W. & HARLEMAN , D.R.F.
" Fluid Dynamics "
Addison-Wesley Publishing Company , Inc., 1973 .

(4) CEBECI , T. & SMITH , A.M.O.
" Analysis of Turbulent Boundary Layers "
Academic Press Inc., 1974 .

(5) DEISSLER , R.G. & TAYLOR , M.F.
" Analysis of Turbulent Flow and Heat Transfer In Non-Circular Passages "
Technical Note TN4384 , National Advisory Committee for Aeronautics ,1958 .

(6) TRACY , H.J.
" Turbulent Flow in a Three-Dimensional Channel "
Journal of Hydraulics Division , ASCE , Vol.91 , No.HY6 , November , 1965 .

(7) VAN DEN BERG , B.

" A Three-Dimensional Law of the Wall for Turbulent Shear Flows "

Journal of Fluid Mechanics , Vol.70 , Part 1 , 1975 .

(8) CHIU , C-L. , LIN ,H-C. & MIZUMURA , K.

" Simulation of Hydraulic Process in Open Channels "

Journal of Hydraulic Division , ASCE , Vol.102 , No.HY2 , February , 1976 .

(9) RAO , G.N.V.

"The Law of the Wall in Thick Axisymmetric Turbulent Boundary Layer "

Journal of Basic Engineering, Transactions of ASME , Ser.D, 89 , 237 , 1967 .

(10) PATEL , V.C.

"A Unified View of the Law of the Wall Using Mixing Length Theory "

Iowa Institute of Hydraulic Research Report, No.137 , Iowa, Apil , 1972 .

(11) DENLI , N.

"Thick Axisymmetric Turbulent Boundary on a Circular Cylinder "

Journal of Hydronautics , Vol. 13 , No.3 , 1979 .

(12) HILDEBRAND , F. B.

" Advanced Calculus for Applications "

Prentice-Hall Inc. , New Jersey , 1976 .

(13) ROUSE , H.

" Advanced Mechanics of Fluids "

John Wiley and Sons Inc. , New York , 1959 .

(14) TAYMAZ , Y.K.

" The Distribution of Wall-Shear Stress , Velocity and the Coefficients of Energy and Momentum in Semi-Elliptical Open Channels "

A Master Thesis Submitted to the Department of Civil Engineering and the Commitee on the Faculty of Engineering of M.E.T.U. , Ankara , 1985 .

(15) GRADSTEIN & RYZIK

" Tables of Integrals and Series "

Academic Press .

(16) PATEL , V.C. & HEAD , M.R.

" Some Observations on Skin Friction and Velocity Profiles in Fully Developed Pipe and Channel Flows "

Journal of Fluid Mechanics , Vol.38 , Part 1 , 1969 .

(17) AFZAL , N. & YAJNIK , K.

" Analysis of Turbulent Pipe and Channel Flows at Moderately Large Reynolds Number "

Journal of Fluid Mechanics , Vol.61 , Part 1 , 1973 .

(18) CLARK , J.A.
" A Study of Incompressible Turbulent Boundary Layers in Channel Flow "
Journal of Basic Engineering , Transactions of ASME , December , 1968 .

(19) BALTA , A.
" End Depth in a Semi-Elliptical Channel "
A Master Thesis Submitted to the Department of Civil Engineering and Commitee on the Faculty of Engineering of M.E.T.U. , Ankara , 1983 .

(20) RAJARATNAM , N.N. & MURALIDHAR , D.
"End Depth for Exponential Channels "
Journal of Irrigation and Drainage Division , ASCE ,Vol.90, No.HY2 , March , 1964 .

(21) DELLEUR , J.W. , DOODGE , J.C.I. & GENT , K.N.
" Influence of Slope and Roughness on the Free Overfall "
Journal of Hydraulic Division , ASCE , Vol.82 , No.HY4 , August , 1956 .